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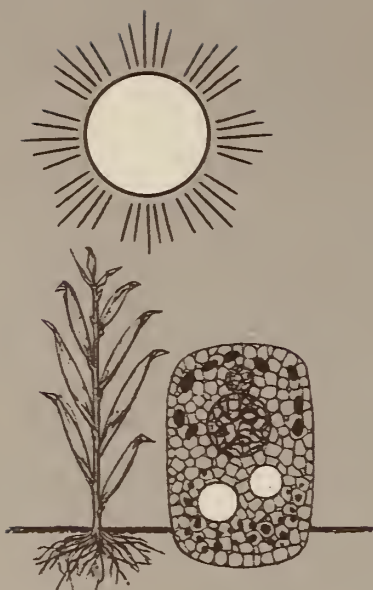
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THIRD QUARTER 1965

COMMUNICATING AND COORDINATING AGRICULTURAL
RESEARCH: A REVIEW OF FEDERAL FACILITIES Page 1



AGRICULTURAL SCIENCE REVIEW

Third Quarter 1965

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CONTENTS

- 1 COMMUNICATING AND COORDINATING AGRICULTURAL RESEARCH
- 18 WHAT IS SCIENCE?
- 24 INSECT GAMETOGENESIS AS A TARGET
- 37 NEURONS, BRAINS, AND COMPUTERS
- 38 NITROGEN FERTILIZERS: PROGRESS AND PROBLEMS
- 48 THE AUTHORS

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Our Changing Patterns

The lead article in this issue of *Review* was designed to provide readers an overall perspective of what the Department of Agriculture and other Federal agencies are doing to improve communication and coordination in the agricultural sciences. We hope it will be informative and helpful. As the article states, the panorama is indeed a broad one. Even with selective pruning of the available information, it is the longest article *Review* has ever published. On two occasions before press time, our staff had to rewrite certain statements from future tense to present tense—so rapidly are changes occurring.

In one sense, this issue of *Review*—and the lead article in particular—may be considered a tribute to Samuel W. Johnson. For it was he who pioneered the American movement for tax-supported research in agriculture. It was Johnson who first proposed high standards for basic research and emphasized the need for coordinated programs.

Over the years, the Johnson formula has acquired new strength and stature, and one of its basic ingredients—coordination—is now shaping into new patterns that just a generation ago might have been considered ill contrived.

Of one fact we can be sure: The patterns of communication and coordination will continue to change. How much, no one knows. The ingenuity and imagination of man, undoubtedly, will determine the limits. Just a matter of months ago, for example, new developments in molecular electronics spawned an optical scanner capable of accurately reading and storing every word and statistic in this journal in seven minutes. Truly, this is not an age for timid planning.

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Communicating and Coordinating Agricultural Research

A Review of Federal Facilities

AMONG the handful of people employed by the U.S. Department of Agriculture in its first year of operation were three scientists, a statistician, and an editor. Obviously, such a small staff experienced few difficulties in coordinating their efforts and in sharing new knowledge. At least we like to think they had no problems when we compare this modest beginning with the vast Federal-State complex of the 1960's.

During the early decades, the process of communicating and coordinating research results among scientists followed essentially the same pattern. Scientists wrote papers, attended professional meetings, discussed problems personally among themselves. Statisticians compiled meaningful statistics, aided only by equipment with relatively minor sophistication. Editors dutifully improved technical papers and published them in bulletins and journals. The process of "diffusion of information" contained in the original act of Congress was conscientiously followed.

But over the years, as the scope of agricultural research broadened things began to change. Scientists were finding it more and more difficult to keep up with the flood of new research findings. The statisticians saw weaknesses in outmoded systems. New communications problems harassed editors and information specialists.

It seems somewhat prophetic that the same professions that formed the nucleus of the Department at its birth are the very ones most affected by the newly emerging problems of the sixties.

By the mid-1940's the complexities of communicating and coordinating problems were already beginning to be a matter of concern to most science disciplines. Noted men of science and discerning science administrators believed they would inevitably face a major crisis in communication between scientists—a crisis that sooner or later would require the abandonment of long-accustomed habits of procedure.

Vannevar Bush, former Director, National

Science Foundation, said:

"There is increasing evidence that we are being bogged down today as specialization extends. The investigator is staggered by the findings and conclusions of thousands of other workers—conclusions which he cannot find time to grasp, much less to remember, as they appear. Yet specialization becomes increasingly necessary for progress, and the effort to bridge between disciplines is correspondingly superficial.

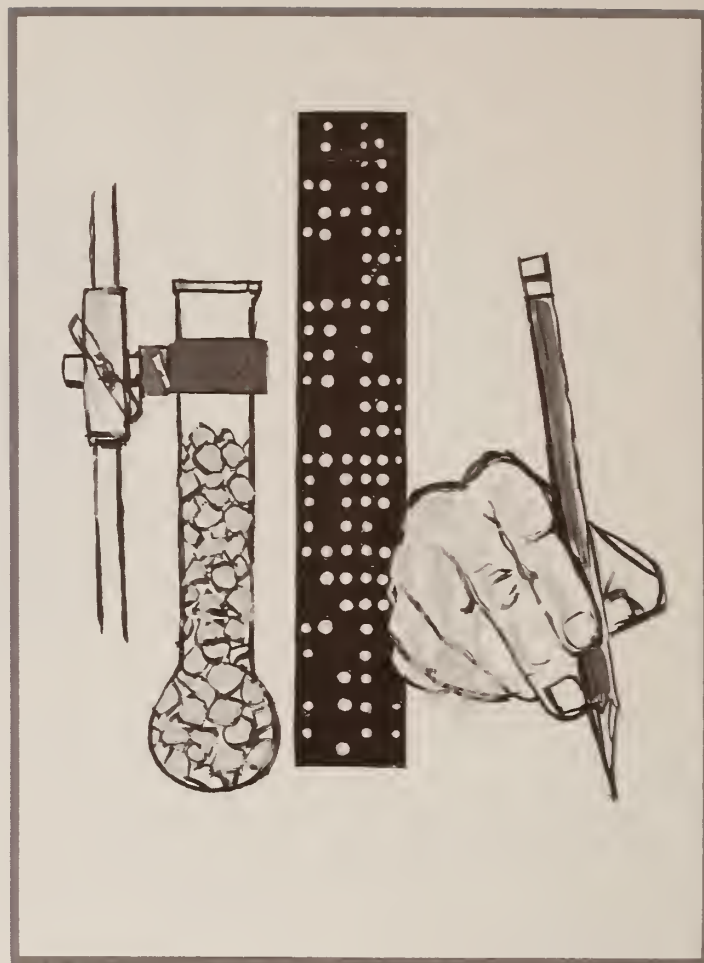
"Professionally our methods of transmitting and reviewing the results of research are generations old and by now are totally inadequate for their purpose. If the aggregate time spent in writing scholarly works and in reading them could be evaluated, the ratio between these amounts of time might well be startling. * * *

"The difficulty seems to be, not so much that we publish unduly in view of the extent and variety of present-day interests, but rather that publication has been extended far beyond our present ability to make real use of the record. The summation of human experience is being expanded at a prodigious rate, and the means we use for threading through the consequent maze to the momentarily important item is the same as was used in the days of square-rigged ships."¹

By 1960 the seriousness of the situation was well defined. An article in *Science* by D. R. Swanson of Ramo-Woolridge Laboratories (now at University of Chicago) described it this way:

"A scientist who nowadays imagines either that he is keeping up with his field or that he can later find in the library whatever may have escaped his notice when it was first written is a victim of what might be called the 'fallacy of abundance.' The fact that so much can be found on any subject creates an illusion that little remains hidden. Although library searches probably seem more often than not to be successful simply because a relatively satisfying amount of material is exhumed, such success may be illusory, since *the requester cannot assess the quantity and value of relevant information which he fails to discover.*

"The sheer abundance of recorded knowledge and the growth rate thereof, furthermore, seem to



Scientist, statistician, and information specialist—each faces an era of unprecedented change in communicating and coordinating research.

foreshadow a crisis of inundation. It is estimated that there are now 100,000 journals and 600,000 scientists in the world, and that these quantities are doubling every 10 to 15 years * * *."²

As might be expected, the agricultural sciences were caught in the same dilemma that gripped other areas of science. The attendant problems lacked no attention, however, from all the agencies concerned. In 1962 the critical issues served as the basis for an agency coordination study by the Senate Subcommittee on Reorganization and International Organizations under the chairmanship of Vice President (then Senator) Hubert H. Humphrey. Titled "Agricultural Research Information

¹ "As We May Think," Vannevar Bush. *The Atlantic Monthly*, July 1945. Used by permission of the author and the publisher.

² "Searching Natural Language Text by Computer," *Science*, 132: 3434, Oct. 21, 1960, pp. 1099-1104. D. R. Swanson. Used by permission of the author and the publisher.

and Communication—A Progress Report,” the study cited trends, needs, symptoms, and causes. The study also pointed out the commendable actions already being taken by Secretary Freeman, his associates, and staff.

This general realization by all groups of the need to add new dimensions to the communication and coordination of agricultural research is gradually producing some significant changes that, hopefully, will bring notable benefits.

In documenting these changes, *Review* makes no serious attempt to come up with a meaningful analysis of which ones carry greater or lesser significance. The panorama is indeed a broad one. Perhaps we must patiently wait for more time and hindsight to evaluate properly the role of each new Federal facility and management plan for keeping agricultural science in step with the demands of the era.

INTERAGENCY COORDINATION

ALTHOUGH the Federal Government has always encouraged and supported interagency coordination of research, new national patterns of information services are evolving into a more effective national system of scientific communication. The Executive Branch has taken several closely related steps toward the attainment of this goal. One of the most important of these was the establishment in 1959 of the Federal Council for Science and Technology. Activities of the Council include: promoting closer cooperation among the Federal agencies, improving the planning and management in science and technology, and advising and assisting

the President regarding Federal programs affecting more than one agency.

Much of the status of the present system of coordination can be attributed to the work of the Council, together with that of the National Science Foundation and other interested groups. However, much credit should be given to the cumulative acts taken by the agencies themselves to strengthen management for their scientific information responsibilities. Most agency managements now recognize that communication of science information is an essential product of their agency's operation. They also recognize that control and dissemination of information is a vital part of research and development. This position represents a fundamental change in the attitude of many agencies over the past 5 years.

The involvement of the Department of Agriculture in interagency coordination affairs has naturally increased in recent years, not only because of new national policies but also because of the ever widening range of disciplines with which agricultural science is concerned.

Obviously, the degree of communication and coordination between the Department of Agriculture and the following agencies will vary from one agency to another. For example, the flow of information between the Science Information Exchange and the Department has a much broader scope than that between, say, the Federal Clearinghouse and the Department. In each instance, however, the extent of participation is likely to increase over the years rather than diminish.

SCIENCE INFORMATION EXCHANGE

IN 1949, rapidly expanding programs in medical research prompted several Government agencies to join in establishing the Medical Sciences Information Exchange. Its mission was to facilitate effective planning and management by promoting the timely exchange of information on the current research activities of Government and non-Government agencies and institutions. During the next few years, related areas of biological research were added to the medical sciences and the name “Bio-Sciences Information Exchange” was adopted in 1953. At that time it came under the direction of the Smithsonian Institution. In 1960 it was re-

named the Science Information Exchange to signify the addition of research information in the physical sciences.

The Department of Agriculture now has substantially all its research projects—about 3,500—registered with SIE. The combined Federal and Federal-State projects currently total about 13,000.

The Science Information Exchange is a clearinghouse for information on current scientific research actually in progress. Government agencies and many non-Government agencies with major research programs actively cooperate by furnishing the Exchange with timely information on their current

research programs and projects. Non-Government agencies include private foundations and fundraising agencies, universities, industry, and individual investigators who wish to register their research. The mission, scope, and policy guidance are formulated by Federal agency representatives, the National Science Foundation, and the Smithsonian Institution. The Director of the Exchange, assisted by a staff of scientists, is responsible for its operation.

The Exchange differs significantly from other library, documentation and technical reference services in several respects. It is concerned only with records of research planned or actually in progress. It does not receive progress reports, abstracts, or other forms of published research results. The Exchange compiles data and technical information for program management purposes at the request of directors and administrators of the cooperating agencies. The Exchange provides broad coverage of basic and applied research in biology, medicine, sociology, psychology, agriculture, and the physical sciences with attention to interdisciplinary reference. All technical information is handled, indexed, and retrieved by a staff of well-trained and experienced professional scientists.

Information about current research tasks is collected from all available sources and put in the form of a one-page record that includes (1) the name of the agency that supports the research, (2) a short title, (3) names of all professional investigators, (4) location of the work, (5) a 200-word summary of the work in progress, and (6) the dollar level of effort, including dates. This record, called the Notice of Research Project, is the basic unit or hard copy record of SIE.

Research records are now coming to the Exchange at a rate of about 100,000 per year—75,000 projects and 25,000 proposals. The major source is the Federal agencies, but other important sources are recognized and are being expanded as fast as staff and resources permit.

Estimates indicate that 90 to 95 percent of all the research in the life sciences supported by Federal agencies is on file at SIE. A substantial part of the physical sciences program has been received and more comprehensive coverage is hopefully anticipated.

The greatest demand for information, of course, has been from the Government agencies that es-



tablished and support the Exchange, but thousands of questions are answered for members of the scientific and engineering community. The latter usually ask for information about who is currently working on a specific problem or project in the user's research specialty. These may be very detailed, such as all current research on the kinetics of conversion of anhydrous boron oxide to boron nitride, or they may deal with broad topics, such as all research on organic semiconductors, or integrated circuits involving silicon.

Questions from research administrators may involve one or all of the six items of information in the task records; the job of providing the answers may vary from being very easy to very difficult.

The easiest type of question is one where a specific, nonambiguous term is being searched for and no formatting of the response is required. For example: "Give me all research projects listing John J. Doe as investigator." Or, "Give me all federally supported projects active at Ohio State University." In each case, the response is a stack of Notices of Research Projects. Only slightly more difficult is a request for all the research records in a given subject area. Professional staff scientists identify the subject points which will yield the pertinent NRP's.

A little harder, now, is the following task: "Construct a table showing all federally supported re-

search in land-grant universities broken down by department." The selection of material is straightforward but the formatting problem now rears its head. For example: Should Federal agencies be lumped or should each component be identified as separate entities; should like departments be lumped or kept separate?

Considerably more difficult is this kind of request: "Construct a table showing all federally supported research in universities by department in the area of animal science." The formatting problem now takes a back seat while the experts argue about the scope of the topic.

Within the limitations noted earlier, SIE can offer comprehensive coverage of all Federal research in

life sciences, but this is the result of years of slow and tedious effort in collecting task records from all available sources. Since the physical sciences collections began relatively recently, they are still far from complete. Incidentally, there seems to be no reliable way of measuring completeness. Some quarters place great importance on completeness; this, of course, is an ideal goal. But it is not immediately attainable even under the best of circumstances, and in the meantime SIE has offered its services on the premises that some information is better than none; that if the user does learn about the existence of research of which he was unaware, he will have received something of value, even though he may have no assurance of complete coverage.

CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION

One of the newest Federal facilities in the communications field is the Clearinghouse for Federal Scientific and Technical Information, which serves as the central source for Government research data in the physical sciences and engineering.

Development of the Clearinghouse was endorsed in February 1964 by the Federal Council for Science and Technology. The Council specifically calls for the Clearinghouse to serve as the single agency through which unclassified technical reports and translations generated by all Government agencies are uniformly indexed and made available to the public. The Clearinghouse provides information on Federal research in progress and operates a referral service to sources of specialized technical expertise in the Government. It has taken over the document distribution program of the Office of Technical Services. Unlike Science Information Exchange, the Clearinghouse operates on a self-sustaining basis insofar as dissemination of material and information is concerned.

The main services of the Clearinghouse include:

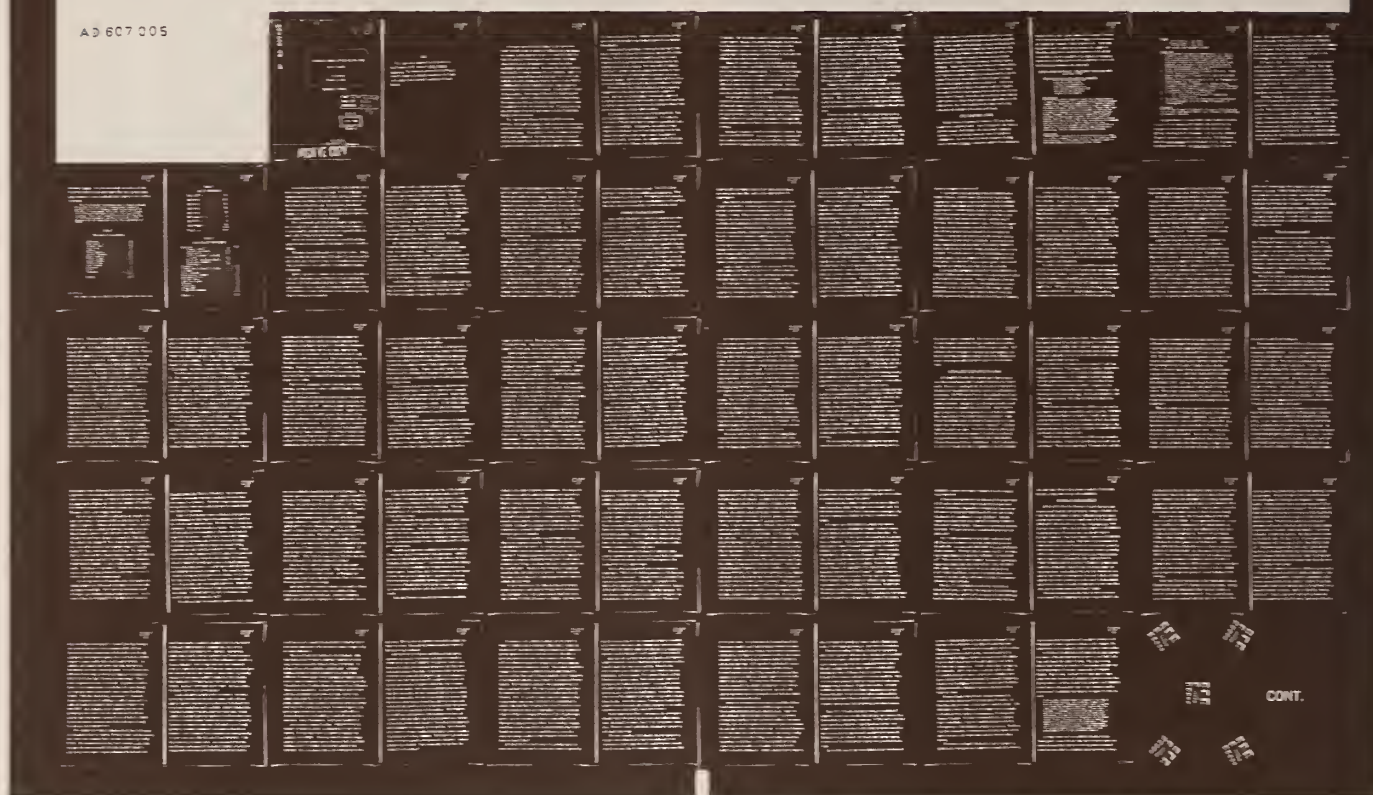
a. Research reports—These consist of reports based on federally sponsored research and development and translations of foreign technical material. After the documents are cataloged and indexed, they are put on sale in two forms, printed pages or microfiche—a 4" x 6" unitized sheet form of microphotography covering up to 70 pages of text. New documents are announced semimonthly in *U.S.*

Government R&D Reports. These include primarily those reports of Department of Defense and other agencies except Atomic Energy Commission and National Aeronautics and Space Administration, which announce their reports separately in other Clearinghouse document outlets. At present, Clearinghouse reports cover research areas other than Federal agricultural and medical research.

b. Government-wide index—The Clearinghouse issues a monthly consolidated index to the Government-sponsored technical literature. The index contains subject, author, source, and report number—the standard points of access to the total report literature. Such an index will permit scientists, engineers, and research managers to scan one publication in reviewing report literature in their fields of interest.

c. Referral service—The Clearinghouse is setting up a master file of sources of information in the physical sciences and engineering. These sources include both Government-sponsored centers and private industry. Inquirers are referred to the sources most likely to have the information needed on a given subject. The Clearinghouse cooperates with the National Referral Center (Library of Congress) in providing the service.

d. Research in progress—The Clearinghouse supplies information on current Government-supported unclassified research and development work in progress. Its aim is to help the industrial and tech-



Here is a full-scale reproduction of a microfiche—a type of microfilm on which can be recorded up to 70 pages of text.

nical community avoid duplication of technical work by announcing who is doing what in the unclassified area of Government research. The Science Information Exchange (Smithsonian Institution) will cooperate in this effort. The SIE and other agencies will notify the Clearinghouse of new research projects. This information will then be cataloged and made available. The service will offer listings by project, title, performing organization, principal investigators, term of contract or grant, and descriptive terms for the new research reported. The file created through input of current research will also be used in general Clearinghouse reference services to answer inquiries in specific areas.

e. Regional dissemination—Technical information contained in selected Government research reports is examined, reviewed, and packaged for industry's use. The resulting packages are distributed

to local groups, such as universities, technical assistance organizations, State and regional economic agencies, professional technical consultants, and others. The packages consist of selected abstracts, indexes, literature reviews, and other information aimed at specific needs.

f. Literature searching service—The service is operated by the Clearinghouse in cooperation with the Department of Agriculture, the Department of the Interior, and the Science and Technology Division of the Library of Congress. The program provides a fast and economical method by which a large segment of the public with special, often urgent, needs for research information can tap these four major Government literature resources. It offers "tailormade" bibliographies suited to the day-to-day as well as long-range information requirements of scientists, engineers, and technical administrators. Steps are underway to make available

under this program the literature resources and specialized information services of other Government agencies as well.

Subscribers to this service can request that a literature search be made by the Library of Congress, the Department of the Interior, the Department of Agriculture or the Clearinghouse, or any combination thereof. If desired, a literature search can be performed by all four agencies simultaneously.

The Science and Technology Division of the Library of Congress covers the published literature of the vast science and technology collection at the Library. The Clearinghouse, acting as an agent, arranges for searches of the science and technology

collections at the Departments of Agriculture and the Interior. In addition, the Clearinghouse searches its own collection of reports derived from Government-sponsored research and development as well as its large holdings of technical translations.

The flexibility of the service accommodates pinpoint research on individual subjects or indepth coverage of broadly related fields.

The Literature Searching Service provides two kinds of bibliographies: (1) "Current Awareness" bibliography for keeping subscribers abreast of new developments on a periodic basis, and (2) retrospective bibliographic searches listing literature available on a subject at the time a request is made.

NATIONAL SCIENCE FOUNDATION

THE 1950 act of Congress that established the National Science Foundation also authorized and directed it to foster the interchange of scientific information among U.S. and foreign scientists and to provide certain types of support to further the dissemination of such knowledge. In 1958, directives from the Congress and from the President extended the Foundation's responsibility to include coordination of national scientific information activities and specified its tasks in some detail.

Title IX of the National Defense Education Act of 1958 directed the Foundation to "provide, or arrange for the provision of, indexing, abstracting, translating, and other services leading to a more effective dissemination of scientific information" and to "undertake programs to develop new or improved methods, including mechanized systems, for making scientific information available." Under this directive, the NSF Office of Science Information Service (OSIS) was established.

The 1958 act also established a 19-member Science Information Council to be an advisory group to OSIS. The Council is composed of six scientists, six experts from the documentation and library fields, and three interested, knowledgeable laymen. The Librarian of Congress, the Director of the National Agricultural Library, the Director of the National Library of Medicine, and the Head of OSIS are *ex officio* members of the Council.

The Foundation has continued to look upon its role in scientific information as coordinating and

supplementing—not supplanting and operating.

OSIS activities are conducted by five programs organized in two sections, as follows:

The Studies and Support Section—includes programs of basic studies, improved processes and systems, and support of communication.

The Science Information Coordination Section—includes programs of Federal science information and domestic and foreign science information.

Studies and Support

RESEARCH and development directed toward systematic and, where possible, mechanized procedures for handling large volumes of scientific information have been supported by the Foundation for a number of years. The objective of the Information Systems Program is to continue this research and development and to extend it through the application of existing knowledge, techniques, and equipment to the design of improved information systems. Work in this area frequently requires the combined talents of many kinds of specialists including linguists, mathematicians, logicians, computer experts, librarians, and information specialists. Support is provided for research, development, experimental applications, and evaluation of systems in the areas of information retrieval, mechanical translation, libraries, and publications. Principal emphasis is on improving the basic understanding of generalized problems rather than on establishing particular systems.

THE Federal science information program has a fourfold mission in the area of Government scientific and technical information: Liaison with other Government agencies, surveys and evaluations, administration, and support.

The program monitors Federal scientific and technical information activities. Liaison is maintained between the Foundation and the scientific information activities of other Government agencies and between the Foundation and interagency organizations on science information matters. Surveys and evaluations are undertaken on the relationships between Federal and non-Federal scientific information activities.

The program administers and supports two major Federal information centers—the Science Information Exchange and the National Referral Center for Science and Technology.

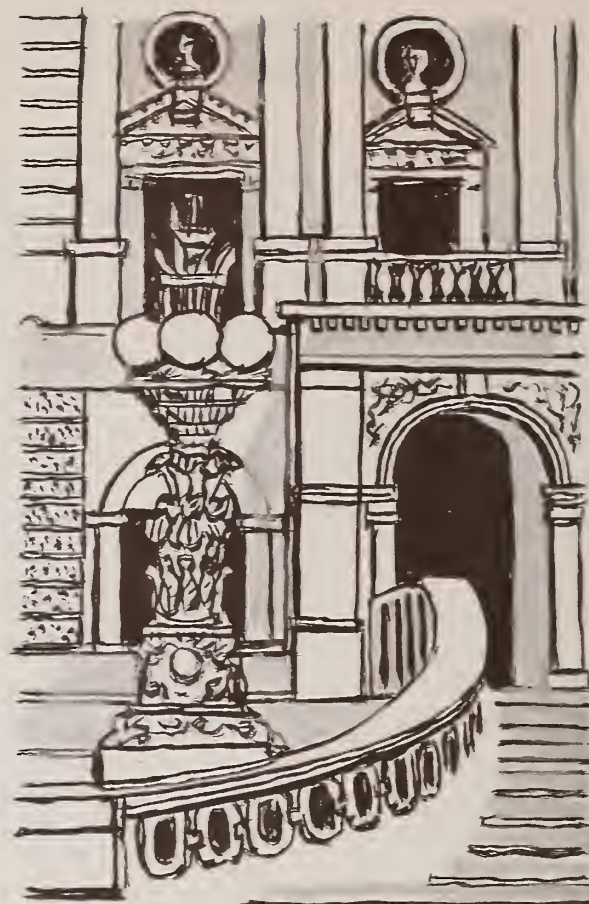
Assistance, where necessary, is provided to certain interagency groups concerned with Federal scientific and technical information activities. These supporting efforts include preparation of studies, recommendations for improvements, and participation in the interagency consideration of such activities.

In general, OSIS efforts for improvements in the relationships between Federal and non-Federal science information activities are based on providing advice, persuading, or acting as a catalyst to bring about significant advances. Funds are sometimes provided, on a short-term basis, for experimental or exploratory projects that would not otherwise receive support.

LIBRARY OF CONGRESS

A NEW directory for scientists and engineers has been published by the National Referral Center for Science and Technology at the Library of Congress.³ Entitled *A Directory of Information Resources in the United States: Physical Sciences, Biological Sciences, Engineering*, the volume describes the subject specialization, information services, and publications of some 1,100 organizations and institutions throughout the country. The material has been

³ See *Agricultural Science Review*, vol. 2, No. 3, 1964, p. 13.



drawn from the growing register of information resources being built up by the center, and represents an exploratory effort at bringing together such diverse elements of the information network as professional societies, academic research groups, industrial firms, Government offices, and technical libraries.

The directory is the first in the National Referral Center's publications program. A volume in the social sciences is in preparation, based on data gathered by the Bureau of Applied Social Research at Columbia University. The Center's plans include specialized listings to meet requirements in selected areas, as well as revisions of the more general directories. Support for the NRC is provided by the National Science Foundation.

Concurrently with its publications efforts, the National Referral Center is continuing to expand its referral services and its register of information resources. Of almost 15,000 potential resources so far identified, the Center has corresponded with about 11,000 and has analyzed and cataloged more

than 5,000 of the replies received. The very general approach taken by the Center initially in establishing this fund of data has been supplemented in recent months by efforts to cover specific subject areas in depth. This work is being conducted in consultation with individual specialists and professional groups who have expressed interest in cooperating with the Center.

In the directory just published, the narrative entries are listed alphabetically by organizational name. In cases where several resources are parts of a single organization, such as a university or Government agency, the individual units are entered alphabetically under the main entry; cross references have been introduced to aid in locating such units. In the subject index the names of the information resources are given below each pertinent subject term to facilitate rapid scanning and identification.

On August 31, 1964, the Librarian of Congress announced the establishment of a new Science Policy Research Division in the Legislative Reference Service of the Library of Congress.

This action thus climaxed a year of congressional proposals to improve its own scientific advisory staffs—proposals that ranged from strengthening existing apparatus to creating new legislative agen-

cies patterned after the White House Office of Science and Technology. All of these initiatives appeared to arise from intensified recognition of the potency of science and engineering to influence and shape public policy; a growing concern over sharply rising R&D budgets; the need for improved information to monitor a complex array of Federal technical activities and budgets; and mounting difficulties in understanding Government-wide programs that cross agency lines so that no one congressional committee has jurisdiction.

The capability of the Division will be extended through collaboration with other specialists in LRS, and use of other departments of the Library, particularly the Reference Department, which has a Science and Technology Division employing a limited staff of specialists in various broad fields of science, and the National Referral Center for Science and Technology.

The new Division also plans to extend its capabilities through consultation with outside authorities on highly specialized problems in science and technology, and discussion with science policy groups such as the National Academy of Sciences' Committee on Science and Public Policy and other groups in engineering and industrial communities.



JOINT PUBLICATIONS RESEARCH SERVICE

THE Joint Publications Research Service (JPRS), Department of Commerce, translates, makes abstracts, and performs foreign-language research for other Federal agencies. Established in 1957, the JPRS has published over one million pages of translated materials comprising some 27,000 numbered reports (an estimated 80,000 separate articles). These materials represent the largest body of current translations—on numerous subjects and from various languages—available to the Government and to the general public.

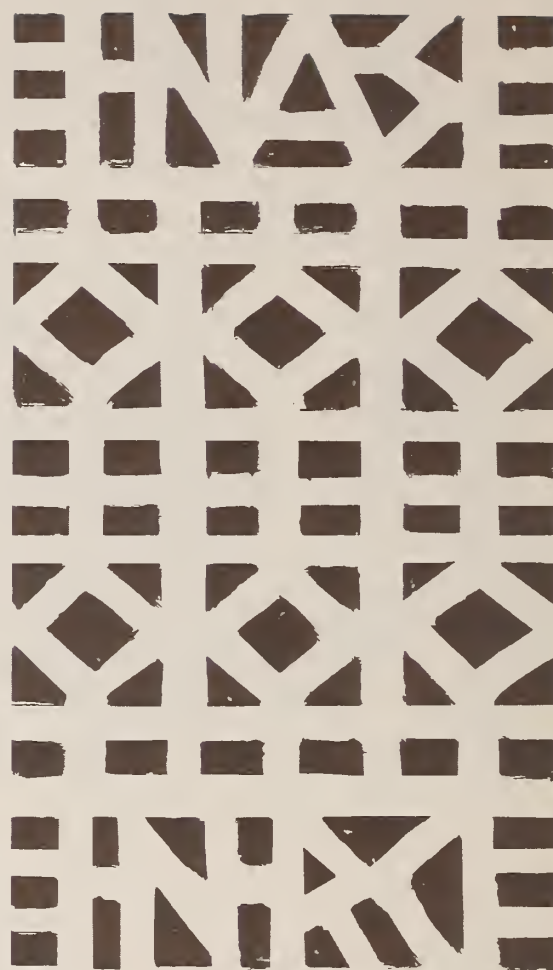
Both written and oral translations are available from JPRS on a reimbursable basis.

THE National Academy of Sciences-National Research Council, a quasi-official agency dedicated to the furtherance of science, has long enjoyed close relations with the Department of Agriculture and other Federal agencies. It does not maintain laboratories, but seeks to support and stimulate the work of individual scientists and to coordinate investigations dealing with broad problems in research.

Although activities of several of the Council's eight subject-matter divisions relate to the disciplines serving agriculture, the Division of Biology and Agriculture, naturally, is most closely associated with USDA. Within this Division, the Agricultural Board studies and provides advice on scientific problems dealing with agriculture and its relation to human welfare. Affiliated with the Agricultural Board is the Agricultural Research Institute, formed in 1951, which provides a forum for unrestricted discussion of problems common to agricultural scientists in government, industry and universities, and important financial support for the work of the Agricultural Board.

The Board and its 13 major committees and 27 subcommittees serve as factfinding and advisory groups, disseminating information on specific projects through a number of publications, many of which have become standards in the field. The Board periodically issues a newsletter which is distributed to members of the Board and the Institute, as well as to a limited number of other interested parties. The Agricultural Research Institute, at its 12th annual meeting in October 1963, recommended to the Board that more attention be given to the organization, abstracting, storage, and retrieval of scientific information in agriculture. It specifically recommended that attention be given to quality indexes for agricultural commodities and to grades and standards for identifying quality characteristics. The Board is presently considering these recommendations.

An example of Committee action is provided by the Board's Committee on Animal Health. One of its projects is the problem of methods and procedures for reporting morbidity and mortality in animals. Present systems are fragmentary and unsystematic, and the formation of a new committee



to develop a practicable comprehensive reporting system is being considered. The Committee would: (1) collect information on the present practices and procedures of the several agencies concerned with animal morbidity and mortality, including the Public Health Service, USDA, U.S. Sanitary Livestock Commission, and the several States and private agencies that have limited programs underway; (2) plan for a comprehensive, nationwide system of reporting animal morbidity and mortality, building on all available useful systems; and (3) develop manuals on materials, methods and practices for the diagnosis of animal diseases.

Space limitations preclude a more complete citation of Academy-Research Council activities and functions. But it should be noted that the Academy-Research Council provides unique means for organizing attacks on scientific problems which involve many specialized fields and for obtaining disinterested and objective assessments of problems for groups with dissimilar or conflicting interests.

AMONG the Federal facilities, groups, and committees concerned with coordinating and communicating science information, one of the newest of those working behind the scenes, so to speak, is the Committee on Scientific and Technical Information (COSATI).

Established by the Federal Council for Science and Technology in May 1962, COSATI is a permanent working group composed of senior Federal department or agency officials responsible for the operation of scientific and technical information systems.

As originally conceived, COSATI was a mechanism primarily to insure, through interaction of the agency representatives, program coordination, development of Government-wide standards, and increased compatibility among information systems. As a result of emerging needs, a new charter in 1964 specified that COSATI would also contribute towards coordination and cooperation with improved Federal and national systems for handling scientific and technical information. Consequently, COSATI has established a Task Group on National Systems for Scientific and Technical Information to consider problems related to national and Federal planning and policy.

The objective of the task group is to prepare recommendations and plans for the development of national information systems to include actions for Government agencies, suggestions for actions by the private sector, and steps to move from current to advanced information systems. It is expected that the availability of a COSATI "blueprint," charting concepts and goals, will facilitate cooperation and participation by Government and non-Government scientific and technical information groups and contribute towards the orderly growth of national information systems.

During the year, a special analysis of the Executive agencies' scientific and technical information programs in the President's fiscal year 1966 Budget was made by COSATI for the Bureau of the Budget and the Office of Science and Technology. Special budget issues of several Federal agencies were analyzed and reviewed for the Federal Council. Steps were taken to move from current to advanced infor-

mation systems. It is expected to reduce duplicative data requirements on Federal R&D agencies. Advances were made in revising definitions and guidelines of scientific and technical information categories in the surveys.

The Committee has sponsored an agreement on a standard photographic form for document storage, including the internal and external dimensions of microfiche. Industry has also accepted some of these standards. The Committee has sponsored the adoption and publication of standards for the descriptive cataloging of technical reports. During the next year both of these agreements will be fully implemented; or compatible arrangements will be worked out by the agencies.

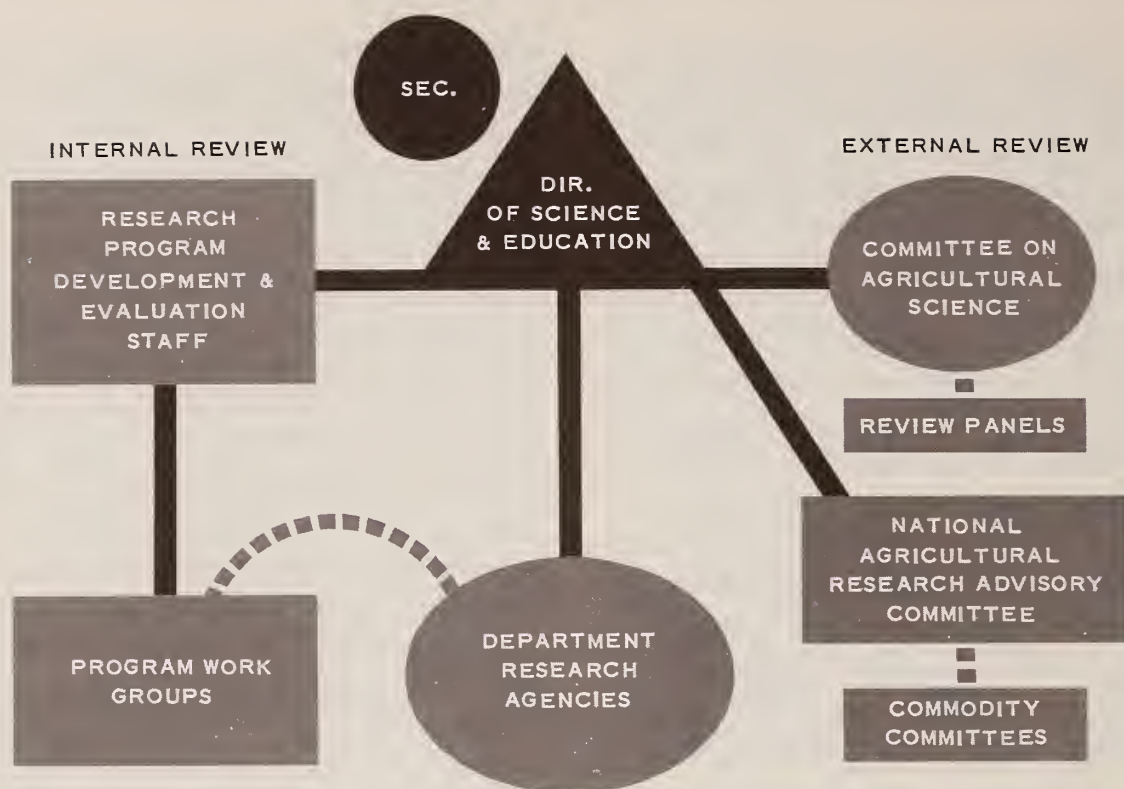
Other COSATI task groups have been formed to study and make recommendations in specific areas. Topics being considered include: vocabulary compatibility, R&D in information science, initial distribution of Executive agency R&D reports, a single Government-depository library system, and descriptive cataloging standards.

To assist in the essential operation of COSATI, Secretary Freeman last year requested each USDA agency to appoint an agency coordinator for science information to provide intradepartment coordination and a means for each agency to keep informed. The Department's representative on COSATI is Foster E. Mohrhardt, Director of the National Agricultural Library. His appointment to the Committee is unique in that he is the only librarian serving on it and he is the only librarian who has been given departmentwide responsibility for coordinating science information activities.

COORDINATION WITHIN USDA

ON the surface, the extremely wide and varied nature of the USDA research program might appear less coordinated than it actually is. As a matter of fact, very successful coordination has been maintained through the Agricultural Research Council, through regional programs with the various State experiment stations, and by cooperative agreements. Most important of all have been the close relationships maintained among the working scientists themselves.

COORDINATION WITHIN USDA



Additional steps have been taken recently to improve even more on research coordination. One of these is the establishment of the new Research Program Development and Evaluation Staff under the direction of the Director of Science and Education. This staff provides for an organized and continuing arrangement for Department-level research planning, including goals, policies, and programs for long-range and emergency needs. They also evaluate the Department's research achievements in relation to planned objectives and the effectiveness of working relationships with other public and private research agencies. This new office will provide the means of giving more attention to the interagency programs . . . and a better organized approach to the Bureau of the Budget, the Congress, and other Federal agencies. The functions of the staff will be carried out in cooperation with research agency leaders.

Another recent step is the establishment of the Agricultural Research Planning Committee. This Committee is made up of six representatives of State universities and land-grant colleges; six representatives from research agencies of the Department,

nominated by the National Academy of Sciences; and one member nominated by the Office of Science and Technology. The vice chairman is a USDA official, designated by the chairman.

The committee has six objectives:

(1) To assist in planning, evaluating, and coordinating unified long-range national agricultural research programs, and in delineating the appropriate areas of responsibility of Federal and State agencies in carrying out these programs.

(2) To develop further the bases for State and Federal cooperation in planning and implementing regional and interstate research programs.

(3) To facilitate the coordination of plans for additional State and Federal agricultural research facilities to carry out the total effort of publicly supported agricultural research.

(4) To stimulate selective interchanges of Federal and State scientists to improve liaison and coordination between Federal and State research programs.

(5) To improve communications among Federal agricultural research agencies, the State stations, libraries, and information centers.

(6) To stimulate and foster training programs for promising young scientists so as to insure a continuing supply of well-trained manpower.

External review and advice for carrying out the Department research programs come from several sources. One is the Committee on Agricultural Science, composed of 15 of the Nation's outstanding scientists. This Committee conducts a continuing evaluation of the research supported by Federal funds, particularly work of a basic nature, with a view to appraising the capacity for significant research. Review panels assist in planning and maintaining cooperation between agencies of the Department and research in closely related fields.

The National Agricultural Research Advisory Committee makes recommendations to insure broad coverage of all important areas in agriculture in the interest of maintaining a comprehensive, dynamic, and flexible research program. This Committee maintains contact with 12 advisory or commodity committees, which review various segments of current research and recommend adjustments. These unique committees, representing all aspects of agricultural problems, offer an ideal system of communication between the Department and consumers and farmers.

USDA RESEARCH PROJECT SYSTEM

A SIGNIFICANT development in the coordination and communication of research information within the Department of Agriculture is the initiation of a study on the feasibility of introducing electronic data processing to improve the efficiency of the Department's research project system. The feasibility study began in 1964 by a task force designated by Dr. Nyle C. Brady, Director of Science and Education.

Major considerations covered by the task force included needs for the development of one overall system, appropriate provisions for information exchange services, and information output essential to research management.

Particular attention was given to:

(1) Current practices associated with the use of the Department's project system in research program planning, budget development, program coordination, reporting, and evaluation;

(2) Procedures and practices for developing input and output of research-related information;

(3) Current practices and programs utilizing data processing systems in connection with research program planning, coordination, and reporting.

In January 1965, the task force submitted its findings and recommendations; these were studied and subsequently approved by Dr. Brady and the agency heads in March. The report indicated that research coordination and communications in USDA could benefit by introducing electronic data processing. However, preparations for the introduction of automation called for unification of policies and processes of the research programs of the Department and the States (where possible) into a single overall systems framework with integrated procedures for long-range planning, annual planning, and research reporting.

USDA agency heads have agreed to a plan for development of a pilot operation which will bring into a single systems framework the research programs of the Forest Service, the Cooperative State Research Service, and two divisions of the Agricultural Research Service—Crops Research Division and Northern Utilizations Research and Development Division. As soon as this pilot system is operative, the remaining research programs of the Department will be brought into the overall system as rapidly as possible.

Two work groups have been set up to develop and implement the pilot operation. One group is working on agency planning and reporting systems; the other on scientific information storage and retrieval.

Currently, the developmental work on agency planning and reporting is concentrated on the "systematizing" aspects. At a later date it is planned to weight the feasibility of well-conceived systematized manual processing versus the potentials of machine processing.

Simultaneous with the systematizing work, developmental work will be undertaken to provide scientific vocabularies and key word and coding systems tailored to meet the needs for scientific information storage and retrieval services to scientists and administrators. Work in this area is being carried out in cooperation with the National Agricultural Library, the Science Information Exchange, and others who have similar interests. These several areas of work are being closely coordinated.

THE National Agricultural Library (NAL) is assuming an increasingly important role in coordinating and communicating science information. Co-operating jointly with two other national libraries—the Library of Congress and the National Library of Medicine—it provides coverage and servicing of worldwide publications in the agricultural, chemical, and biological sciences. At present, its volumes number about 1,230,000—probably the most extensive agricultural collection in existence. Publications are acquired in more than 50 languages from 150 different governments and their instrumentalities.

In addition to providing the normal services related to the needs of research personnel, NAL activities, facilities, and plans include the following:

Task Force ABLE

IN 1962 with the cooperation of the Office of Management Appraisal and Systems Development, USDA, Task Force ABLE (Agricultural-Biological Literature Exploitation) was established to design and present in detail the concepts of an information retrieval system for NAL. A comprehensive plan has been developed, and the first stage in the Library's projected system was presented in the August 1964 issue of the *Bibliography of Agriculture*. The next phase of the *Bibliography's* mechanization calls for the application of the same optical scanner-computer combination for the production of a monthly subject index and an annual cumulative subject index. This index requires more complex systems designing and programing, and a target date of January 1966 has been set. All surveys, plans, systems design, and programing have been handled by USDA personnel, an unusual approach in information storage and retrieval mechanization.

NAL is considering using a second section of the *Bibliography of Agriculture* to announce new research projects together with the name and address of a reliable source (probably the project leader) for current information concerning each project. When implemented, this arrangement should give scientists throughout the country access to unpublished research information. Additional sources of unpublished research information will be included later. NAL is also developing a single agricultural-

biological indexing vocabulary for use in the *Bibliography of Agriculture* and the Library card catalog.

NAL Clearinghouse

TO avoid duplication of effort and provide increased availability of bibliographies, translations, and studies on mechanized information systems, NAL has established a clearinghouse to serve USDA and State research personnel. Under the system, the Library maintains records of agricultural bibliographies or translations being compiled or prepared throughout the United States as well as documentation studies or systems. Any requester has access to this information, in return for which the Library asks only that copies of completed bibliographies or translations and information concerning mechanized information activities be transmitted to it and made available through its program to scientists all over the world.

Control Mechanism

THROUGH NAL, the Department of Agriculture has established a control mechanism to prevent competitive and duplicative efforts within the Department in its program for the exchange of scientific and technical information. Thus, NAL has Departmentwide responsibility for setting up all USDA publications-exchange arrangements with foreign governments, organizations or individuals. More than 200,000 pieces are being sent annually to 7,468 organizations in 151 governments and jurisdictional entities. The return flow brings to the USDA about 216,000 pieces each year. Working closely with the International Agricultural Development Service, USDA, and the Agency for International Development, the Library assists foreign nations by developing and arranging a year of study and training in library technics in the United States, after which the participants return to their homelands to apply this much-needed knowledge.

Pesticides Information Center

ONE of the newest facilities in USDA's stepped-up program of research and education is the Pesticides Information Center in the National Agricultural Library. Its establishment by Secretary Freeman in March 1965 marked a significant advance in making available masses of scientific and technical

information on pests and their control. Already under consideration are additional science information centers to serve other subject-matter areas.

An important resource of the Center is a bi-weekly publication, the *Pesticides Documentation Bulletin*. One of the primary objectives of the *Bulletin* is to inventory the multidiscipline literature in the pest control fields and disseminate it to interested personnel in the Department of Agriculture and other Federal departments and State, private, and industrial organizations.

The *Bulletin* is an index to the literature on pests and their control and the impact on the economy and man's total environment. The index includes literature on diseases, insects, nematodes, parasites, weeds, and other pests affecting plants, animals, man, our natural resources, and other values in man's environment. Literature on biological, chemical, cultural, ecological, mechanical, and integrated methods of pest control are included. Special emphasis is given to the literature on the biological, toxicological, physiological, biochemical, pathological, biophysical and epidemiological aspects of pests and their control by chemical and nonchemical methods.

The publication is available without charge to libraries, educational and scientific institutions, agricultural associations, Federal and State officials, Department employees and workers in agricultural colleges and experiment stations.

Documentation Service

ONE of NAL's long-range goals is establishing a continuing nationwide network for agricultural biological documentation services. This includes strengthening of acquisitions and cataloging activities; expanding bibliographic coverage; broadening lending, photocopy and reference services; proper maintenance of the collection; and cooperative arrangements with land-grant institutions. The first delegation of national responsibility for collecting publications and giving library services in a special subject area has been made through an agreement between NAL and the University of California at Davis. The agreement represents a cooperative endeavor to make available for use by the world's scientific community the most comprehensive collection of agricultural machinery catalogs and related materials in the United States.

NAL is also planning to make its public card

catalog available in book form to other libraries, industrial firms, and research agencies and institutions on a worldwide basis. To include more than 1½ million author, title, and subject cards interfiled in alphabetical arrangement, the publication will probably be the most comprehensive agricultural catalog ever published. Target date for publication is mid-1967. It is estimated that the set will contain about 68 volumes. Copies must be ordered from the publisher and will not be available through the Government Printing Office, exchange arrangements, or as gifts.

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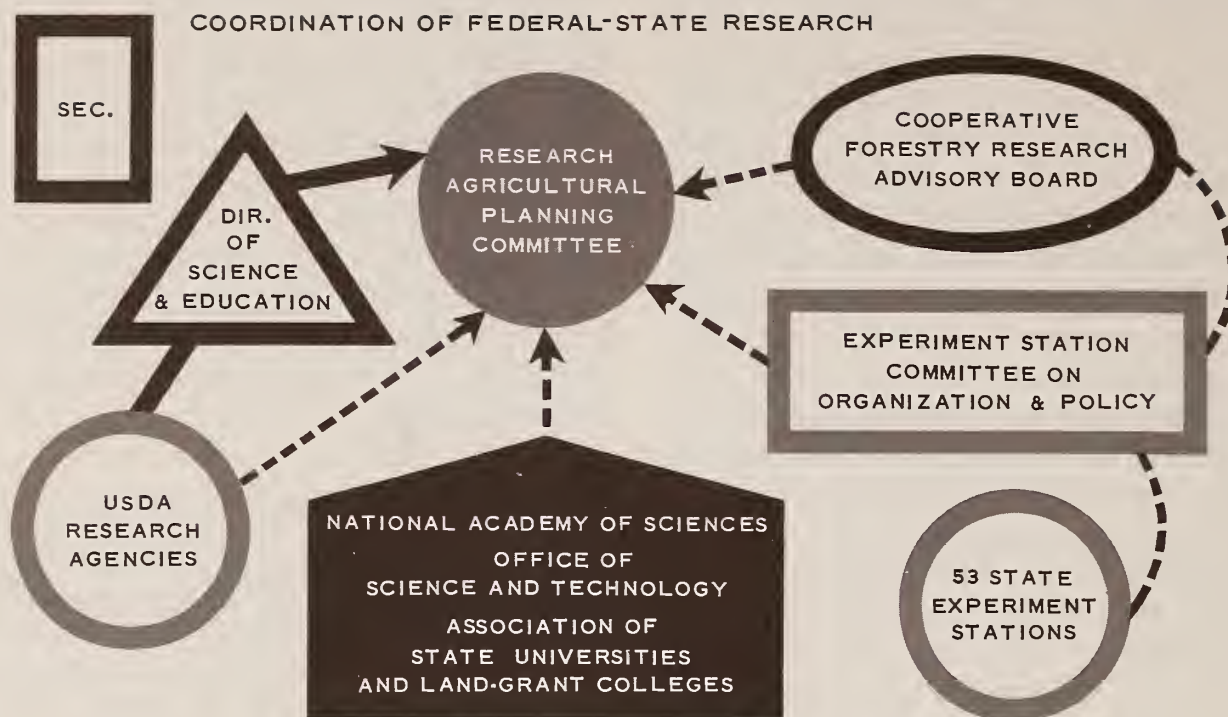
The National Agricultural Library is working with representatives of the Public Health Service, National Library of Medicine, and the Directors of Libraries of the University of Missouri, Texas A. & M., and Michigan State on the possibility of establishing a nationwide information center for veterinary medicine. The project is being coordinated with the American Veterinary Medical Association.

COORDINATION OF PROGRAMS ON PESTS AND THEIR CONTROL

PROBABLY no other research area reflects such depth of coverage and treatment in communication and coordination aspects as that of pests and pesticides and their control. The program reflects the concern of both the Congress and the Department of Agriculture in more effectively coordinating research, regulatory, education, and information activities within the Department and among other Government agencies.

Responsibility for departmental coordination of pesticide programs has been assigned to a pesticide coordinator in the immediate staff of the Secretary of Agriculture. He has initiated programs to enhance close liaison and cooperation between Federal, State, and industrial organizations with responsibilities in the pesticide field.

In 1961 the Secretary invited the Departments of Interior, Defense, and Health, Education, and Welfare to organize the Federal Pest Control Review Board and to assign personnel to work with USDA on interdepartmental coordination of pest control programs. This board was replaced in 1964 by the Federal Committee on Pest Control (FCPC). In reorganizing the board, the FCPC was given broader



responsibilities for interdepartmental coordination of programs on pests and their control. However, the primary responsibility of the FCPC is to review Federal pest control programs to assure that effective and safe methods are used.

In addition to FCPC, the Departments of Agriculture, Interior, and Health, Education, and Welfare have negotiated a three-way agreement in which the departments have agreed to maintain liaison on all programs involving pests, pesticides and pest control. One of the primary objectives of the three-way agreement is to provide an opportunity for the Departments of Health, Education, and Welfare and Interior to review all applications for the registration of pesticides under the provisions of the Federal Insecticide, Fungicide, and Rodenticide Act.

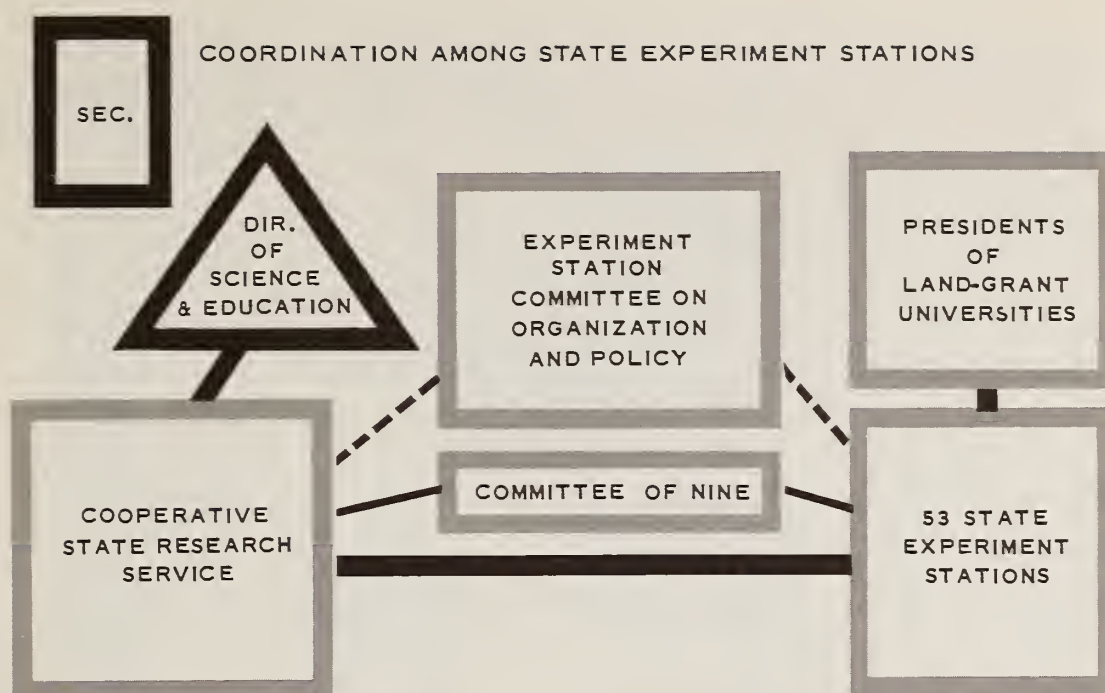
The Department of Agriculture has also established a Pesticide Research Work Group, a Pesticide Control Work Group, and a Pesticide Executive Committee to aid in departmental coordination of programs on pests, pesticides, and other pest control methods.

The primary responsibility of these work groups and the executive committee is to provide a mechanism to facilitate an interdisciplinary and interagency approach to the planning, conduct, and coordination of departmental programs and related fed-

erally supported programs in the land-grant institutions. The work groups and executive committee are also responsible for reviewing and evaluating these programs to determine their adequacy. They also make recommendations to provide effective pest control practices that insure adequate protection of the public health, wildlife, soil, water, forests, and other values in man's environment.

USDA-STATE COORDINATION

COORDINATING Federal-State research might appear to be a major task when one considers the parts of the structure—the land-grant colleges and universities, the State agricultural experiment stations, the several agencies of the U.S. Department of Agriculture, and the several hundred State and Federal stations at different locations throughout the Nation. Much of the responsibility for such coordination rests, naturally, with the Cooperative State Research Service (CSRS), particularly for that segment of research assigned to State agricultural experiment stations and financed by Federal funds. CSRS also serves as the chief agency for communicating and coordinating research among the State stations. On a broader basis, the recently established Agricultural Research Planning Committee provides a strong base for coordinating the research programs of all these agencies.



Currently, the Department of Agriculture maintains detailed records of some 3,700 Department research projects. The Cooperative State Research Service maintains similar records on approximately 6,700 State-supported projects, and 6,400 projects financed all or in part by Federal funds administered by CSRS. Both sets of records provide the background information of current work against which all proposed new projects to be supported by Federal funds are examined. This is the key to effective coordination and prevention of unnecessary duplication.

As discussed elsewhere in this article, plans are underway to have the records of the State-supported projects, Department projects, and Federal-grant

projects fully automated, and located in one place. This will involve extensive voluntary cooperation on the part of the experiment stations in providing information on State-supported projects, over which the Department exercises no control. The improved system for maintaining research project records will provide a source of communication between scientists on all aspects of current research programs. And it will provide comprehensive information to permit ready analysis of research for more effective management.

Facilities for communicating and coordinating research within the State experiment stations are well established, and have often been cited as suitable models which other agencies might well follow.

* * *

Whatever new developments lie ahead in the communication and coordination aspects of agricultural research can only be classed as educated guesses at this point. Certainly, some new developments might rightfully be expected—be they minor or major, run of the mill, or excitingly different. It seems inevitable, however, that whatever new facilities are added in the future will be largely determined by the ultimate potential of our human resources—not that of machines or computers.

WHAT IS SCIENCE?

In the following article,¹ a distinguished historian of science examines some misconceptions that have led to the idea of two antagonistic cultures and advances some thoughts on science as a part of all creative intellectual endeavor.

THE works of C. P. Snow have made the phrase, "the two cultures," a commonplace. Sir Charles has called attention to a relatively modern phenomenon—namely the growing gap between the sciences and the humanities, or perhaps one should say, the scientists and the humanists.

Many people may feel that this is a natural consequence of the growing specialization in the modern intellectual world. After all, there are gaps now between, say, biologists and physicists that did not exist in the 18th century, simply because of the extraordinary rapid growth of modern science. In fact, to raise the question *What is science?* may even seem superfluous.

Does it really matter? Is not science, as James Conant once put it, merely rather sophisticated common sense and does not everyone know what science is by considering it simply as the way of learning about nature? The question is not so easily answered, and it raises a number of extremely practical problems. For example, science and public policy are now becoming a field of extraordinary importance. Not only are the scientist and the engineer being subsidized by the Federal Government to an extent hitherto undreamed of, but they are increasingly influencing public opinion.

Military policy has been subjected to scientific analysis. There is the constant hope—in some quarters at least—that the social sciences will be able

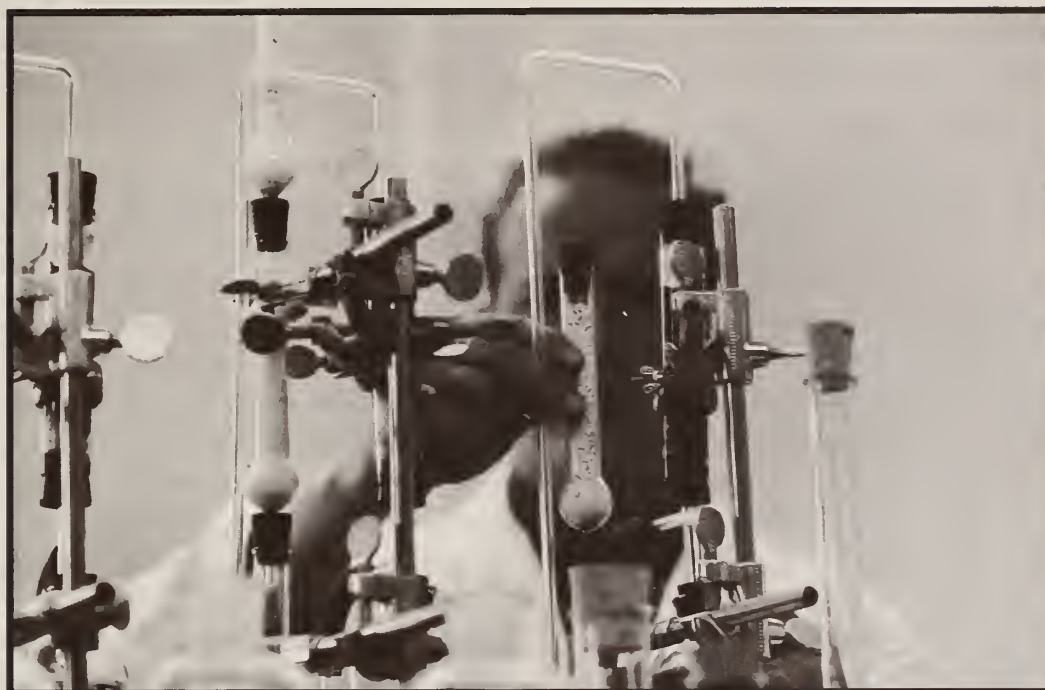
to create social engineers who will be able to construct new systems to solve those social problems that affect us. All this is done in the name of science. Therefore, the way in which we define science will have an important effect on the way in which science is done. Finally, of course, science is the model of all knowledge.

Uniting the Two Cultures

THINGS today are considered intellectually respectable insofar as they are "scientific." The older, established, scientific disciplines have no difficulty here, for no one would deny the basic scientific aspect of physics or chemistry or even biology. But, as new disciplines are born from the increasing complexity of modern civilization, their practitioners, naturally, wish to be as scientific as possible. To do this they look to the older and more developed sciences. In short, they try to create sciences from the image of what they believe the traditional sciences to be. What is this image? Is it valid? Does it do science a disservice?

There are three definitions of science which, in increasing order of complexity and sophistication, are accepted by most people today. Each is insufficient, and I should like to suggest that by accepting any one of these definitions we necessarily dilute and pervert the historical meaning of scientific progress. I would offer a fourth alternative which

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preserves for science the creativity of the arts, together with the scholarly tradition of the humanities. If accepted, it can serve to unite the two cultures that Snow has mentioned and to reveal that science is part of the general intellectual and scholarly endeavor in which Western Man has been engaged for some five centuries.

Science as an Organized Body of Knowledge

The first definition, often offered to young people in high school just beginning their studies of science, states that science is an organized body of knowledge. There is, to be sure, a certain appeal to such a neat definition. It gives the impression of order, of clarity, and of information available at one's fingertips. There is no doubt that science is, of course, an organized body of knowledge, but so is every other intellectual field. This is really a taxonomist's definition or perhaps that of a specialist in information retrieval. For what it means, and only what it means, is that science does deal with facts about the world of physical reality and that the facts can somehow be found with relative ease. I can perhaps illustrate this point by using the Manhattan telephone directory as an example. Here, after all, is a magnificently organized body of knowledge. Some millions of facts can be found with ease. Yet, it would be ludicrous to suggest that the Manhattan directory is worthy of the Nobel Prize.

Answers to Unasked Questions

SINCE information, by and of itself, seems not to be of the essence of science, perhaps we should turn to another criterion—the method of arriving at scientific truth. Here we shall find there are a number of different methods.

The first is known as Baconianism or induction. I think one should apologize for what has been committed in the name of Sir Francis Bacon, the great philosopher of the 17th century. The Baconian method tends to be interpreted today as that method which consists in the collecting of facts for themselves. This, I think, Bacon would have rejected. But given this historical apology, the method does seem to characterize a great deal of what goes on in modern science. This theory of scientific method states simply that the scientist collects and determines facts as accurately as possible. When these facts on a particular subject reach a certain critical mass, they are expected then to blow up into a theory.

There are a number of interesting consequences if this definition of scientific method is followed. In the first place, it is this method which, by and large, has given birth to the modern scientific paper. This is, of course, a minor point, but it should be noticed that one of the things that repel the humanist is the extraordinarily flat prose of the standard scientific paper. Everything is impersonal, everything is reported—usually in the passive

voice—and the result is a flat, dreary plane. This is all done in the name of objectivity. After all, why not? Since facts are impersonal, since facts may be objectively determined, then why should the scientist intrude himself upon the scene? He is merely the reporter of what goes on in nature, and this should be done with the minimum of personal involvement.

The second important consequence leads to one of the truly modern diseases of science. This is the multiplication of factual information at a rate so rapid that no one can keep up with it. One need only skim through a journal such as *Nature* or *Science* to realize the enormous volume of purely factual papers that are being turned out today. One may argue that all facts are potentially useful, and this is probably true. But what always seems to be forgotten is that these facts do not have the same lifespan. Much of what is published is forgotten within a year or two, and the effort that went into it has been wasted.

Why are these facts not incorporated into the corpus of science itself? The reason would seem to be that they are answers to questions which no one asked. Yet on the philosophy that science is fact, then facts should be determined and modern laboratories determine them at an ever increasing rate.

Lines of Communication Clogging

THE phenomenon of factfinding is also intimately related to the emphasis today on publication for promotion in both universities and industrial and governmental research laboratories. A paper is an entity, and the number of papers can be measured accurately. A man's status as a scientist can, therefore, be estimated by the number of papers he has published. For, once again, since all facts are equal the man who discovers the most facts and describes them in the largest number of papers must, by definition, be a better scientist than the man who discovers fewer. The nefarious influences of this trend are only now beginning to be felt, but they threaten to clog the lines of communication within science to such an extent that truly important papers may be lost in the shuffle.

No Room for Qualitative Science

PERHAPS the most important consequence of the philosophy of science which insists upon the primacy

of fact is that it leads to dogma. We are constantly being told that science is open-ended, ever-changing, constantly being revised. But if one looks at these statements in view of the emphasis on facts, the question almost immediately arises as to how this can be so. Facts are not matters of opinion. They either are, or they are not. For a person to challenge the inductive scientist involves challenging his honesty or his competence. This means that inductive science is a dogmatic science. It has very little room for change, for the facts speak for themselves and, once determined accurately, there should be no room for argument. This is the reason science finds itself constantly in the peculiar position of being forced to change without quite understanding why. This is why there is so much resistance to change in some of the sciences.

We can point to physics as the exception that will perhaps prove the rule. The physicists who have lived through the relativistic revolution are all well aware of the aspects of science which do not simply refer to facts, but which do involve a kind of vision of physical reality. Physics, then, today has a tendency really to be open-ended.

Yet turn one's gaze upon the social sciences and one is struck with a picture of almost musk oxen simplicity. There are certain social scientific models which seem to be based strongly on fact. To challenge them is to turn the social scientists, horns outward, in a complete circle to protect what seems to be the foundations of their study. This, in its worst form, is the legacy of the inductive philosophy of science.

From the physics of the late 19th and 20th centuries has come a very abstract theory of what science is, which, nevertheless, has had an exceptional influence on the development of other sciences besides physics. It made its first appearance in thermodynamics, which is concerned with relations between measurable quantities and does not have to deal with any essential substratum which produces these quantities. For example, thermodynamics treats differences in heat or in temperature and does not have to concern itself with the question of whether heat itself is a motion of molecules or a separate fluid. The differences in heat, the ΔH , can be measured and can be operated upon. Similarly in atomic physics, particularly in spectroscopy, one deals with the intensity of spectroscopic radiation, its polarization and its frequency.

These entities can be worked with to predict new spectral lines without any necessity of postulating a theory of light. Therefore, it has been suggested, science is really mathematics; the essence of physical reality is to be found in mathematical equations. What one does is to observe physical facts accurately and then operate upon them by mathematical means. In this way, new relationships are then subject to experimental verification or refutation. Reality becomes the equation itself.

In the first place, this view of reality violates our common sense. To this the nuclear physicist can only shrug his shoulders and insist that that's the way the particles bounce because, in fact, the world of nuclear physics is not a world of commonsense and our commonsense does break down. But if this is true of nuclear physics, is it not true of all areas of science itself? The answer would seem to be, no. But it involves one important point that should at least be considered before being accepted uncritically. The point is this: That since mathematics is of the very essence of science itself, then only those sciences which turn their attention to quantification will become mature sciences. In other words, unless one can reduce science to precise measurement which then permits the substitution of physical or biological or sociological data in an equation that can be operated on mathematically, then the study is not scientific. There is no room, really, for qualitative science in this scene.

The Humanist Repelled

THERE is a good deal of evidence to indicate that this is not necessarily the way science must develop. Michael Faraday, one of the great physicists of all time, was a mathematical illiterate and his contribution to physics was a qualitative one. What he saw was that forces of nature must be intimately interrelated and that these forces could best be compared and examined by suggesting a field theory to replace the theory of particles in motion through empty space that had been dominant to his time. In physics today, the quantitative view certainly is predominant. But must it be so in all sciences? Must biology become quantified or are there not some qualitative questions that may be asked about differentiation of tissues and embryological development, for example? And if one asks

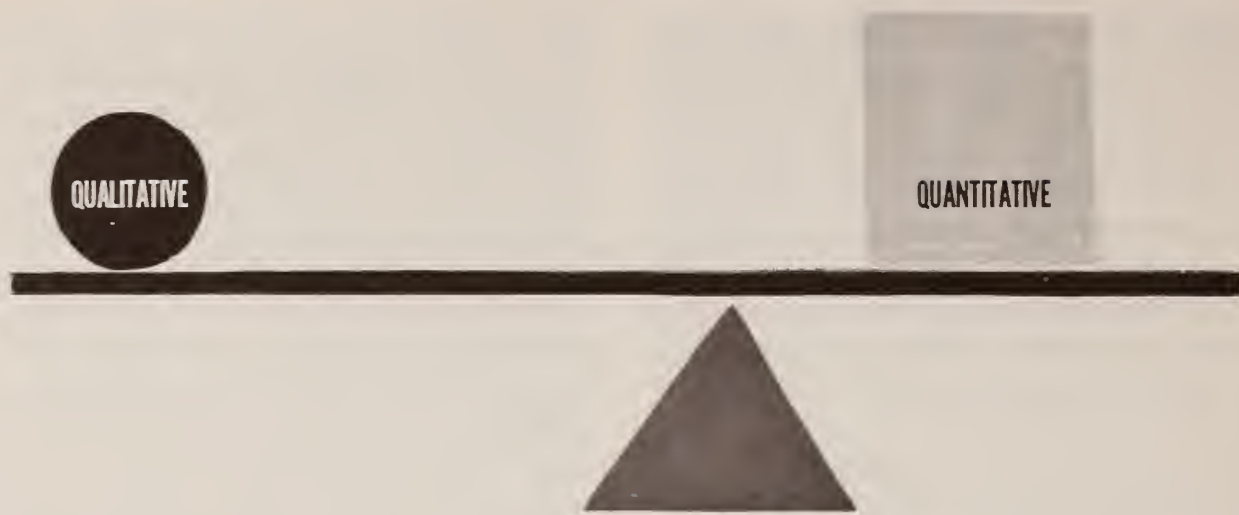
this question of the social sciences, then the true evil of this definition becomes apparent. Those things about human beings which can be quantified are precisely those aspects which are least interesting. We are interested in the quality of a human being, not in his quantitative relationships. This attempt to qualify sociology or political science has led to the multiplication of what, I think, can only be called pseudoscience. It is a science of misplaced concreteness, which identifies certain aspects of human behavior with certain quantifiable parameters and then proceeds to create a society based upon these mathematical essences, ignoring the other aspects of human behavior which are of equal if not greater importance. Here also is the implicit superiority of computation.

There is a certain vague menace in the use of the computer today, and one of the reasons we feel menace is because of this theory of science as being the quantitative or mathematical relationship between bodies. What repels us is the mechanical aspect of it. What we find abhorrent is that we are considered to be organisms of complex chemicals, caught in a super social machine, and capable of being analyzed *in our totality* by an ever-increasing sophistication of mathematical instruments. It is this inhuman aspect of mathematization—particularly of human behavior—that repels the humanist and increases the gulf between the members of the two cultures.

Best Tool for Detection of Error

WHAT, then, shall we consider science to be? Let us admit right away that it is, of course, a body of organized knowledge; it is, also, a collection of facts; and it most certainly is the use of mathematics to express relations between facts. But, these are parts which together do not make up the whole of science, and it is the whole of science which now, it seems to me, must attract our attention. While it will be impossible to give a definition of science which will cover every contingency, I would like to suggest a definition that has about it the elements which the scientist will recognize as important aspects of his work and which have not been sufficiently stressed in modern descriptions of science.

I shall put the definition in the form of an epigram. Science is the best tool yet devised by the human mind for the detection of error. Now, what



does this mean? It means that science and scientific theories are essentially ideas created by the human mind to account for physical reality in as accurate a way as possible. When man looks about him he tries to find an order which is not immediately apparent. Elements of his environment are chosen as important and used to create some kind of a theory of physical, political, or even theological behavior. What is unique about science is that it is capable of being refuted—that is, scientists have developed extraordinarily sensitive tools for blowing up their own theories. This is where the collection of fact is involved, for a well-determined fact may be sufficiently pointed to burst a high-flown scientific theory. This, too, is where mathematics has its place, for the rigorous logic of mathematical manipulation is such that it will exclude purely verbal errors and can reduce an argument to its barest essentials. Thus it is that mathematics or quantification permits the extreme use of an important critical tool, but notice that mathematics or quantification is not essential to the advance of science. A theory can be refuted without the use of mathematics; mathematical formulae merely make it easier to do so.

Let me expand upon my epigram by use of a metaphor. Let us consider science to be equivalent to architecture in an architectural enterprise in which a group of men come upon a heap of stones that seem to indicate that this was once a building. Among the group of men present will be those who have an architectural mentality. They will see in these stones a pattern and, from a few of them, suggest that perhaps this was once a cathedral. With this clue they can now direct their coworkers to gather stones together to fill in the only sketched-in plan. Thus, the stone seekers will be alerted to the

possibility of the finding of a buttress, or perhaps of the altar, on indeed of looking for those pillars which upheld the entire structure.

Interplay Between Architect and Critic

THUS, it is the architect who directs the cooperative search for the stones that fit. But, this is not the history of science. For to continue the metaphor, what has happened is that critics of the architects have pointed out, as the building was being reconstructed, that the architect is wrong. This is not a cathedral, as Michael Faraday might have said, but a railroad station—in the 19th century, such confusion was entirely possible. But then as the “railroad station” of field theory was being constructed, still other critics pointed out that the plan was going awry, and that the stones that could be already seen in the edifice could be rearranged perhaps to build a skyscraper and so on. Thus, the essential interplay in science is the interplay between the architect and the critic, between the man who sees the building in its entirety—however dim the outline—and those who, while fitting the stones into place, have to chisel a bit here and there to make the stones fit or, perhaps, stand back from the whole building and suddenly see it as an entirely different edifice.

If this view of science be a correct one, then it has much to recommend it over those philosophies which, as I have already suggested, have serious drawbacks. In the first place, it puts primary emphasis upon the creative idea of the scientists and not on the existence of the stones. The stones, to be sure, are there, but they are so shaped that they may fit into a number of different plans and it is up to man, to the creative scientist, to apprehend

what plan best fits the stones he has at hand. This, now permits the unification of the two cultures.

Science Must Be Capable of Refutation

THE artist or the humanist and the scientist can be seen to be working roughly within the same framework. The artist tries to assemble the pieces of his experience into an artistic vision; the humanist tries to assemble the collected bits of cultural experience into a vision of humanity; the scientist attempts to assemble the bits of physical reality into a coherent vision of the universe. All are creative in the sense that the whole they create is far greater than the pieces of which the whole was constructed.

Secondly, the critical aspects of science make it relatively free from dogma at the dead hand of authority. If, in fact, the rules of the game are such as to encourage the destruction of theories and hypotheses, then science is truly open-ended. There can be no reliance here upon the great man, for to err is indeed human and no man has ever been exempt from this bit of humanity.

Thirdly, we have seen that mathematics has its important place, but as a critical tool—a way of testing the vision. This test may be in the predictions that mathematical equations will make, but these are all intended to “show up” rather than to “show” the phenomena.

Finally, this definition of science lays down a basic rule which is often violated and which often leads to serious confusion. What it states is that science must be essentially capable of refutation. In other words, scientific statements must be capable of being shown up. The best illustration I can give of this is to recall the reminiscences of Karl Popper who suggested this view of science. He was a student in Vienna in the period immediately following World War I when three very exciting intellectual currents were prominent in Vienna. There was, first of all, the new relativity theory of Albert Einstein. There were also the theories of psychoanalysis of Sigmund Freud and the excitement of Marxism as the new science of the state. All claimed to be scientific. Yet Popper felt, almost intuitively, that there was something wrong with a definition of science which permitted all three to be considered equally scientific.

Then, in 1919, the dramatic test of Einstein's theory of relativity was made. Einstein had predicted the bending of light in a gravitational field.

The eclipse of the sun had shown that this in fact was what happened. Popper recalls his own excitement as he suddenly realized that had the light not been bent by this gravitational field of the sun, all the elegant mathematics, all the abstract reasoning of Einstein would have been for nought. His theory would have been refuted. Yet this cannot be done for psychoanalysis or for Marxism. The Freudian and the Marxist can always give you an explanation. They have the “answers” for all phenomena and their systems, therefore, are irrefutable. They have become dogmatic and closed systems of thought, since they cannot generate within themselves the necessary pressure to change.

Greater Emphasis on Ideas

I SHOULD like to conclude by pointing out the practical consequences of accepting Popper's view of science. In terms of the public support of science, it would mean a greater emphasis on ideas rather than on facts. This could be done simply by insisting emphatically upon the relevance of a piece of scientific work to an explicit hypothesis or theory. Acceptance of this view would also have a revolutionary effect upon the teaching of science at all levels up to graduate school. Instead of the present amoeboid approach in which the student is expected to wrap himself around increasingly large bundles of facts, there would be substituted a method which emphasized the dialogue between the creative scientist and Nature. This, I am convinced, would preserve for science those students who weary of committing the whole of the universe to memory and drop out along the way.

The effect of adopting this view upon the social sciences would be earth-shaking. Once again the social scientist would have to pursue the question of the *nature* of man, not just the *quantifiable* nature of man. A truly humane social science might then become possible. Finally, and perhaps most important, the “two cultures” would disappear.

Our civilization depends for its very life today upon its intellectual resources. Anything which weakens or dilutes these is ultimately harmful. The modern breach between the sciences and the humanities has done just this—to the detriment of the sciences, the humanities, and society. If the essential unity of all intellectual endeavor can be made manifest, then we may expect a surge of mental activity that, like the Italian Renaissance, may well usher in a new age of human history.



Insect Gametogenesis As A Target

Niilo Virkki

MODERN cytology is a quite ramified science that shares interests with genetics, biochemistry, physiology, systematics, and has found extensive application in practical sciences like medicine and agronomy. *Insect cytology* is less diversified than that of vertebrates, especially of man. In insects, the main attraction has been the chromosomes. This is no wonder, because technically the group is very suitable for such studies. Together with plants, insects have been the main source of the present knowledge on chromosomes.

As soon as chromosomes were realized to be related to heredity, the discipline of *cytogenetics* was born. More accumulation of data was needed before cytology was able to attend to the systematics, but nowadays we already speak of *cytotaxonomy*. The major part of present-day insect cytology works with a systematical background, associated with a growing interest in evolutionary and even zoogeographical questions.

I will not discuss to a great extent these main fields of insect cytology in this paper. Rather, the purpose is to point out the growing need of informa-

tion on the cytological characteristics, partly extra-chromosomal, of *gametogenesis*. As the last part of the germ line, gametogenesis forms the genetic gateway to the next generation. Therefore it has become the target of treatments that should affect the progeny. Students of mutagenesis have treated it with ionizing rays or with chemicals, preferring genetically well-known insects like *Drosophila*. Clinically, it has been treated also in man to produce a temporary aspermy and infertility, before the radiation hazards were better understood. Finally, agricultural and medical entomologists have successfully eradicated whole populations of pest insects by inducing lethal mutations in the male gametogenesis.

In insects, the gametogenesis is the usual type of diploid organisms, the gametes forming immediately after meiosis. Female gametogenesis is *oogenesis*. In the female, the meiosis and the differentiation of the egg occur simultaneously. Male gametogenesis is *spermatogenesis*. Spermatogenesis includes the *spermiohistogenesis*—the postmeiotic metamorphosis which results in spermatozoa.

INITIATION AND COURSE OF GAMETOGENESIS

WHEN gametogenesis of a cytologically little known insect is to be treated, certain problems of orientation arise. First of all, in which part of the life cycle does the gametogenesis occur? Further, is the gametogenesis as a whole a sufficiently limited target, or could certain parts of it be more sensitive or yield results of a special character? If the latter is true, when do the useful stages occur with the highest frequency?

These questions concern characteristics of considerable variation. As a rule, the initiation and course of gametogenesis should be checked in every species. Some information, of course, can be found in literature. Radiosensitivity of different phases of

gametogenesis and premeiotic mitoses has for several years intrigued geneticists, and much data have been published. Quite an amount of descriptive data concerning gametogenesis of different insects has been collected in the earlier cytological literature. Unfortunately, such descriptions are usually limited to the cellular sequence from premeiotic stages to the gamete, but do not give the initiation and duration of the whole gametogenetic period in the gonad. A wealth of observations has been made by chromosome researchers, but little has been published because the chromosomes have been their main object. Even so, it is possible to collect valuable hints for treatment of gametogenesis from the earlier cytomorphological literature.

Concerning the initiation and duration of spermatogenesis in insects, the general rule is that it starts

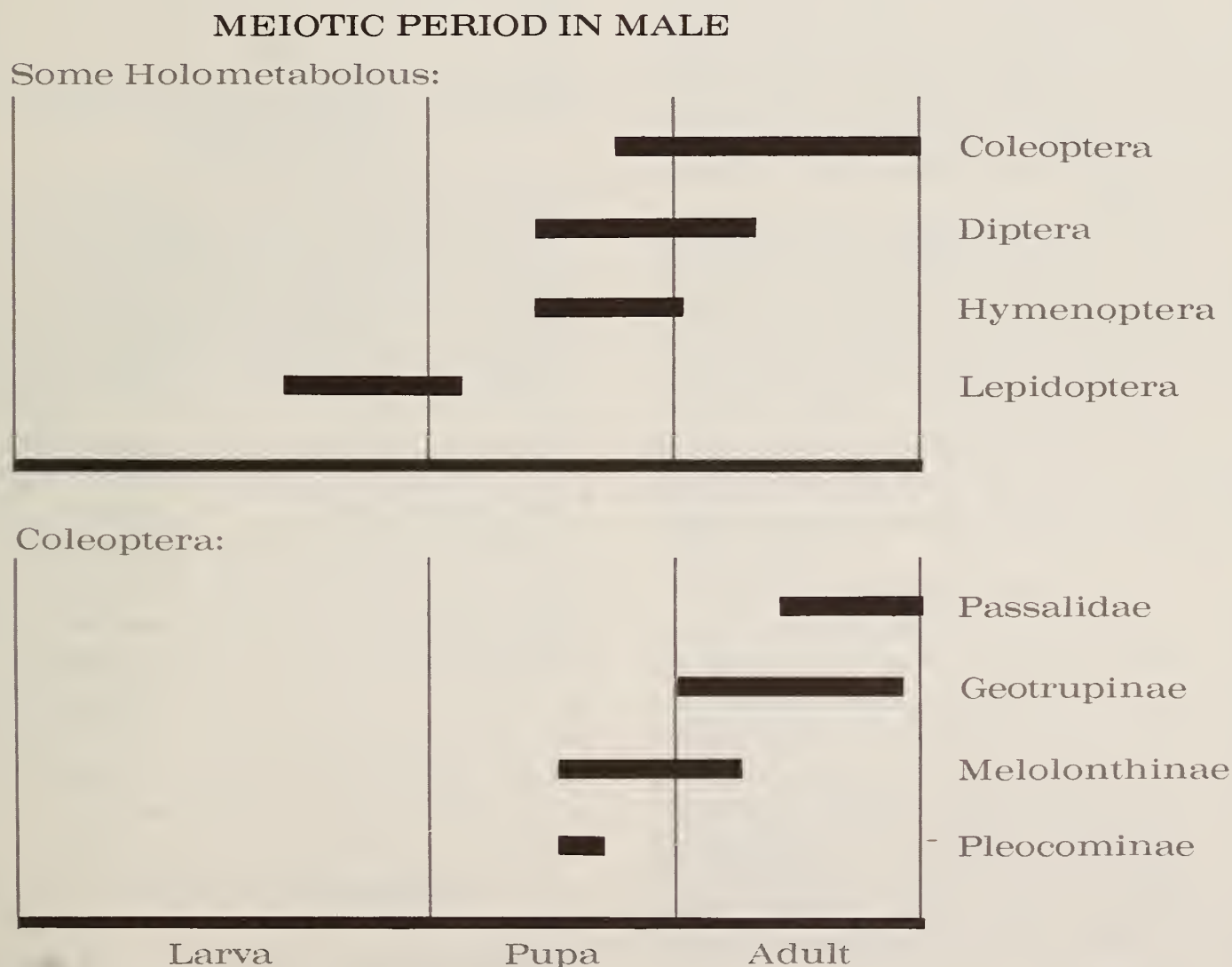


FIGURE 1.—INITIATION AND DURATION OF SPERMATOGENETIC PERIOD IN SOME HOLOMETABOLOUS INSECTS.

in the pupa, and young adults have it in full force. But this is not always so. Figure 1 compares some holometabolous insect orders and some beetle families or subfamilies in this respect. In coleopterans, the spermatogenesis initiates in the pupa and continues in the adult life. In Diptera, the beginning is earlier and the duration probably shorter, although it extends to the adult life. Hymenopterans show initiation of spermatogenesis at the time of pigmentation of pupal eyes; the process probably continues until the adult. Lepidoptera is the most exceptional order; the spermatogenesis starts in the last larval instar, or earlier, and turns to abnormality at the beginning of the pupal life.

Comparison of the four beetle groups shows much variation within an order. Young adults of Passalidae have spermatogonia but none occur in later stages. Adult geotrupins usually have a large reservoir of spermatogonia (germarium), and meiotic divisions and spermiogenesis proceed little by little. Melolonthines differ much from this scheme. Their meiosis starts early in the pupa, and there are species where the whole process terminates before the adult life—like *Melolontha hippocastani* in Finland (29).¹ Finally, the Pleocominae initiate and complete their spermatogenesis in a short period of the pupal stage.

It is obvious that the mode of how spermatogenesis starts and proceeds has much to do with the life cycle and habits of the insect. Thus, passalids are beetles that may live several years, well protected in rotten wood where they form social groupings; they apparently are in no need of a rapid maturation. When the spermatogenesis starts, it proceeds slowly and lasts probably the remaining part of life. There may be other unknown factors determining the late initiation in this strange family.

The geotrupins also are long-living insects. They have a spare-type spermatogenesis, destined for several breeding periods. In the fall, the process is blocked in the early stages (until pachytene) of meiosis, but starts again after the hibernation. On the contrary, melolonthines have a short adult life and must complete their spermatogenesis early. In Pleocominae, the adult life is for propagation only; adults do not even feed. Accordingly, the spermatogenesis passes as one big wave, early enough to obtain the total amount of sperm for the short adult period.

¹ Italic numbers in parentheses refer to "Literature Cited" p. 36.

Climatic conditions also affect the initiation and course of gametogenesis. Thus, beetles of subarctic regions, like Canada and Scandinavia, have their spermatogenesis early in the spring; later in the summer the process weakens or stops. On the other hand, adult males of tropical coleopterans practically always have spermatogenesis. The early, concentrated spermatogenetic period of subarctic beetles obviously depends on the short breeding period. Sperm supply must be early and abundant. This requirement is little pronounced or is completely lacking in the tropics.

Fewer observations are available from the female. The initiation and duration of the oogenetic period are comparable with those of spermatogenesis. However, much fewer eggs are produced than spermatozoa and the meiotic prophase is enormously prolonged because of the cytoplasmic synthesis. Generally, adult females have all prophasic stages in their ovaries. Meiotic divisions coincide with the oviposition and the entrance of spermatozoon.

PROMISE OF EXPERIMENTAL CONTROL OF GAMETOGENESIS

GAMETOGENESIS can be experimentally controlled to some extent. As mentioned above, in long-living northern species winter blocks the spermatogenesis. The spermatocytes beyond the pachytene disappear gradually and some accumulation of pachytene occurs. If the exposure to cold is sudden, the occurrence of phases may remain unaltered for months, as was found in an elaterid, *Agriotes mancus* Say (30). If we prefer to eliminate stages later than pachytene for the treatment, or cause a prolonged standstill of the process, we could probably do it with a cold treatment. According to many recent studies, photoperiodism controls diapause and also initiation of gametogenesis. Thus, it seems feasible that the contents of the testes is at least partially controllable for selective treatment of different phases of spermatogenesis.

CYTOLOGICAL OUTLINES

BEFORE turning to the question of differential stage sensitivity, we need to recollect the course of gametogenesis in some detail.

ALTHOUGH these preparative mitoses are not included in the proper concept of gametogenesis, they should be taken into account in treatment of the latter. They are clearly related with meiosis.

Germ cells located in a young gonad are little differentiated, have a relatively big nucleus, and remain a long time in interphase. They are called primordial gonidia. Intriguing groupings are soon formed in the male. In Lepidoptera and Coleoptera, primary spermatogonia maintain first a cytoplasmal contact with a giant cell, apical or Verson's cell, which seems to be a late offshoot of the germ line. In Hemiptera, the secondary spermatogonia derived from one primordial gonium remain joined by long stalks, forming rosettelike groups where the mitochondria concentrate in the center of the rosette.

In all insects the spermatogonia derived from one primordial gonium become surrounded by a closed envelope of epithelial cells—the so-called spermatocyst. The spermatocyst persists through the whole spermatogenesis. As the number of cells is doubled by each division, the total amount of spermatozoa in a cyst is determined by the two meiotic divisions plus the number of spermatogonial mitoses. The latter varies according to the species. Practically, 7 mitoses is the maximum, resulting in 512 spermatozoa per cyst after meiosis. The lowest number of spermatogonial mitoses, found in some tropical alticids, is 2, resulting in 16 spermatozoa per cyst.

Such groupings apparently have some kind of common control over the cells involved; probably the synchronization of the spermatogonial mitoses in a cyst is one result of it. From our point of view, such groupings may have a common vulnerability as well. The spermatocyst, being a closed envelope, certainly can protect its contents against changes in the surrounding liquid.

In the female, such groupings are lacking, but ovarian eggs, encapsulated together with nurse cells, may be comparable groups.

In undifferentiated, meristematic or embryonic cells, the synthetic activity of interphase is directed to the reconstruction of the cell reduced to half by the mitosis. Obviously, the germ cells prior to the primordial gonidia have belonged to this type of cells. From now on, the differentiation begins. It has

been suggested that the prerequisites for meiosis are developed little by little during the gonial mitoses (15). It is common in insect spermatogonia that the cell size, relative nucleus volume, and chromosome size get smaller in every successive generation of spermatogonial cells. The decrease of chromosome size is due to progressive compactness rather than to decrease of the quantity of DNA.²

Meiosis in the Male

THE product of the last spermatogonial division—the spermatocyte of first order (spermatocyte I)—is a small cell which soon starts growing and showing an early but slow process of chromatin contraction. Growth continues always through leptotene and pachytene. This is sometimes called the first growth period of the spermatocyte I. In some insects, as in many Orthoptera, this is also the only growth period; the final size is reached by diplotene. But in many others, a more or less developed second growth period follows in diplotene. This growth is sometimes very conspicuous and leads to giant-size spermatocytes. Nuclear growth is much less than the cytoplasmic growth. Mitochondria are abundant in these cells, often called auxocytes. Very big spermatocytes have been reported in such systematical groups remote from one another like Ostracoda, Chilopoda, Orthoptera, Trichoptera, and the beetle family Scarabaeidae. It seems probable that a similar condition can develop in any invertebrate group. Undoubtedly in such cases, female trends of cyte growth are not completely suppressed by the realizators of the male sex, the result being a diplotenic growth like in oocytes, although less in extent.

In addition to reducing the chromosome number one-half, the first anaphase of meiosis results also in daughter cells half the former size. These daughter cells—the spermatocytes of second order (spermatocyte II)—do not grow or grow only slightly. The degree of intermitotic chromosome spiralization is very variable in this phase. It has been suggested that the interphaselike interkinesis and the second growth period of spermatocyte I are alternatives: Presence of one impedes the other

² Personal communication from O. Halkka. In: *Cytophotometric Studies on the Spermatogonia of Nepa Cinerea (Hemiptera)*. Proc. XIth Intern. Cong. Genet. 1, 6.10. 1963.

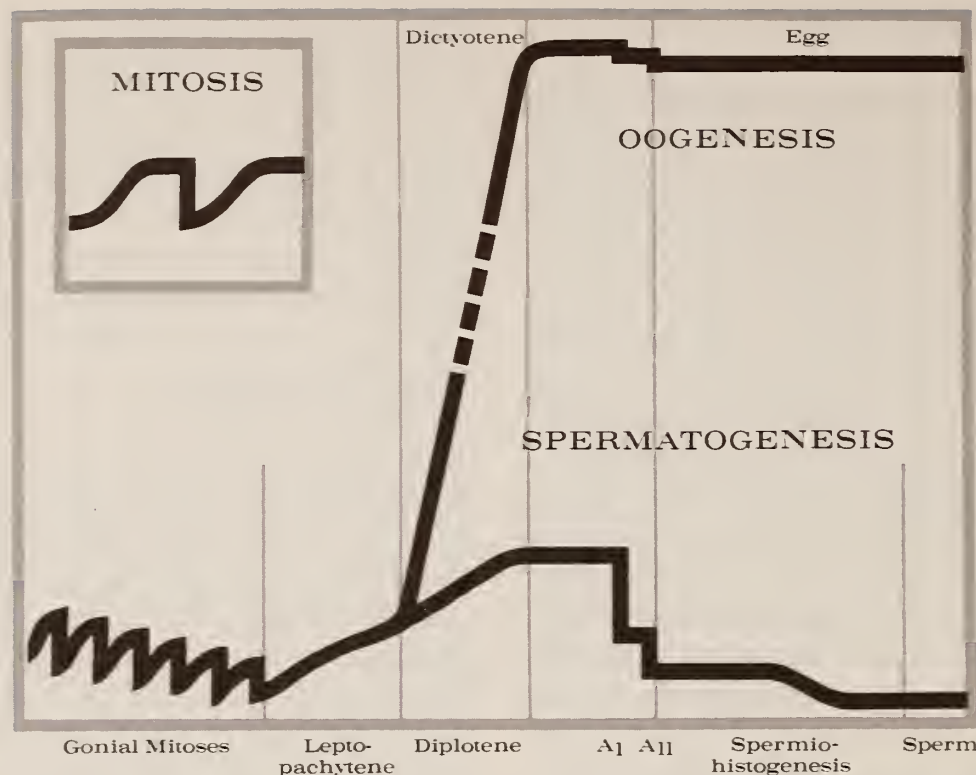


FIGURE 2.—CHANGES OF CELL VOLUME DURING GONIAL MITOSES AND GAMETOGENESIS. *Insert:* Cell volume during meristematic or embryonic mitoses. Original volume, reduced to half by anaphase, is always completely recovered in interphase. *Gonial mitoses:* In successive gonial the cell size is reduced because of incomplete recovery of volume during the interphase. *Lepto-Pachytene:* First meiotic growth period. *Diplotene:* Second growth period in the male. *Dictyotene:* Oocyte growth. *A1 and AII:* Reduction to $\frac{1}{4}$ of the spermatocyte I volume, and insignificant reduction of the oocyte volume by polar bodies. *Spermiogenesis:* Radical reduction of spermatid volume by discharge of cytoplasm.

(25). The second meiotic division results in two spermatids that must pass the spermiogenesis before they become functioning spermatozoa.

Meiosis in the Female

UNTIL diplotene, there is no marked difference between the cellular outlines of the male and female meiosis. The enormous growth of the egg is due to the intensive and prolonged cytoplasmic syntheses in diplotene, or dictyotene, as this phase is often called in the oogenesis. In the major part of dictyotene, the chromosomes remain unspiralized or partly spiralized (so-called lamp-brush chromosomes). The length of this phase is extremely variable—from a couple of days to 50 years at least (in some vertebrates).

The oocyte I of insects enters to the first meiotic metaphase at the time of oviposition. Both meiotic divisions follow in a rapid sequence, but normally not before the sperm has entered the egg. When the meiosis has passed, the egg is laid. Because the

oocyte divisions are extremely uneven (the polar bodies being so small), the size of the egg is not essentially different from the size of a full-grown oocyte I. All polar bodies remain inside the rather strong shell of the insect eggs.

Figure 2 gives the course of gametogenesis in terms of cell volume.

Spermiogenesis

CONTRARY to the eggs, which are fully formed after meiosis, the spermatids have to undergo one of the most surprising cellular metamorphoses known—the spermiogenesis (fig. 3). The mitochondria concentrate to form a knot called "Nebenkern." The centrosome divides in two, and one of the halves organizes a flagellum. The whole cell body begins to elongate. During these processes the spermatids are still included in the spermatocyst which dates back to early gonial stages. The spermatocyst not only passively elongates with the spermatids, but participates in the metamorphosis in its own way. One of the cyst cells begins to en-

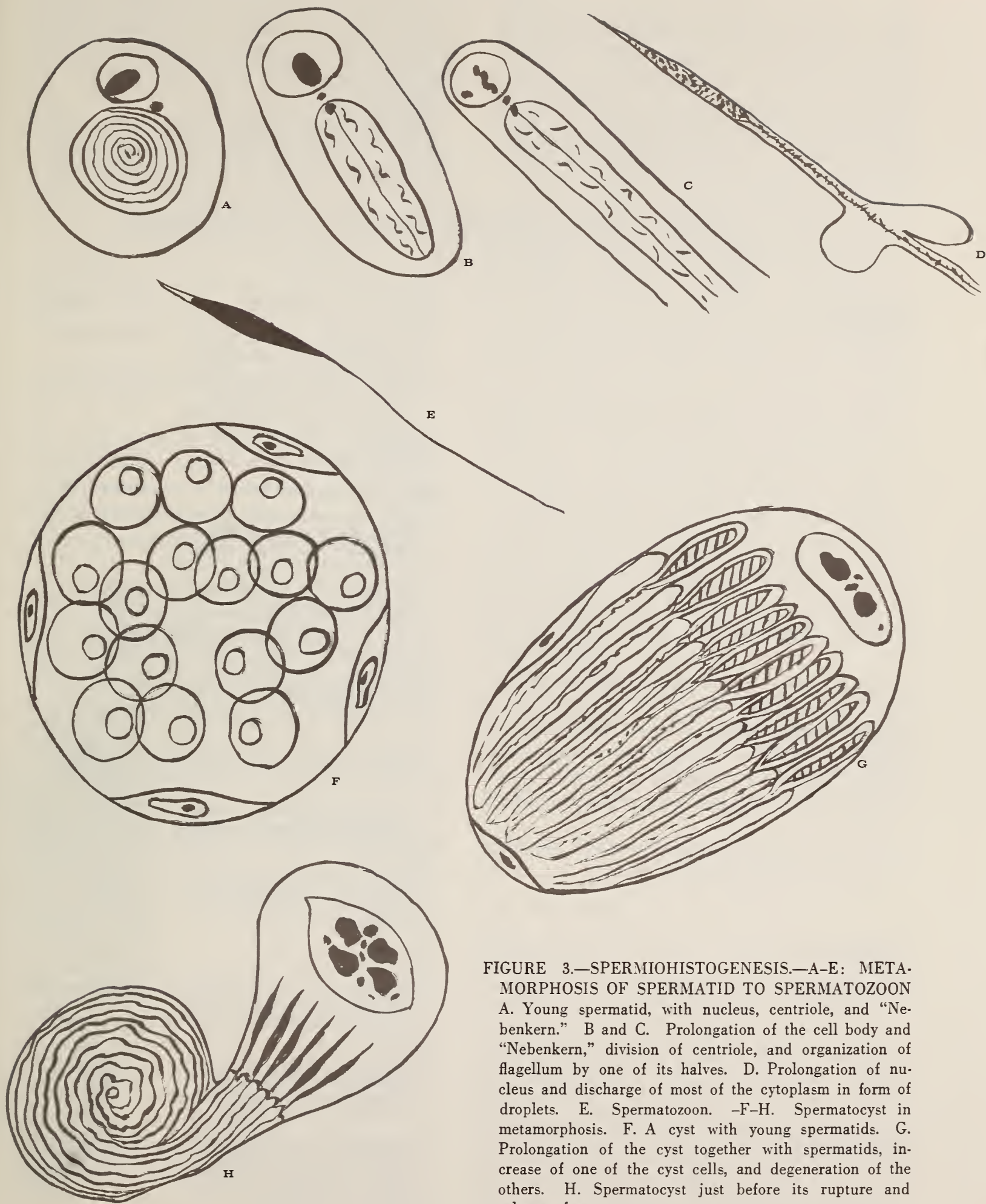


FIGURE 3.—SPERMIOHISTOGENESIS.—A-E: METAMORPHOSIS OF SPERMATID TO SPERMATOZOON. A. Young spermatid, with nucleus, centriole, and "Nebenkern." B and C. Prolongation of the cell body and "Nebenkern," division of centriole, and organization of flagellum by one of its halves. D. Prolongation of nucleus and discharge of most of the cytoplasm in form of droplets. E. Spermatozoon. —F-H. Spermatocyst in metamorphosis. F. A cyst with young spermatids. G. Prolongation of the cyst together with spermatids, increase of one of the cyst cells, and degeneration of the others. H. Spermatocyst just before its rupture and release of spermatozoa.

large. The spermatid nuclei, or future sperm heads, become embedded in the growing cytoplasm of that cell. The cytoplasm of the spermatids is shed away almost completely as droplets which are probably incorporated in the growing cyst cell. The end result of the metamorphosis is a package of parallel, long spermatozoa. The heads are still embedded in the cyst cell; the tails are still lined by the very

thin membrane formed by the weakened walls of the rest of the spermatocyst. The spermatozoa are liberated from the cyst and the big cyst cell at about the time they leave the testis. Species vary in this respect, however.

Nothing certain is known of the function of the cyst cell. It is likely that, as in the groupings of spermatogonia, it controls the simultaneous proceed-

TABLE 1.—RADIOSENSITIVITY AND RADIATION EFFECTS ON THE SPERMATOGENESIS

Organism	Spermato- gonia	Auxocyte	Meta- phases	Sperma- tids	Sperma- tozoa	Observations	Author
<i>Drosophila mela- nogaster</i>	—		—	+	—	Spermatids most sensitive.	Fritz-Niggli (6).
Do.				+	+	Spermatids more sensitive. Domi- nant lethals, point mutations, gynandromorphs, hyperploids.	Lüning (12).
Do.					+	X chromosomes more sensitive in receptaculum of female than in the male. Recessive lethals.	Bonnier <i>et al.</i> (1).
Do.				+		Sex-linked lethals, translocations. . . .	Oster (16).
Do.		+	+	+		Spermatids: recessive lethals.	Strangio (23).
Do.	+	+	+	+		Gonia: Crossovers, sterility; Auxo- cytes: Sterility, translocations; Spermatids: sex-linked lethals, translocations.	Kvelland (11).
Do.	+	+				Gonia: aspermy. More sensitive than meiotic prophase.	Welshons <i>et al.</i> (32).
Do.	+			+		Gonia: Crossovers, necrosis; Sper- matids most sensitive.	Chandley <i>et al.</i> (3).
Do.	+	+	+			Early meiosis most sensitive for Xy-nondisjunction.	Sävhaugen (19).
<i>Corthippus longi- cornis.</i>	+					Varying chromosome breakability. . .	Creighton (4).
<i>Bombyx mori</i>	—	+		—		Dominant lethals, induced apyreny. .	Kogure <i>et al.</i> (10).
Do.	+	+				Varying sensitivity depending on cell stage; spermatogonia highly sensitive.	Tazima <i>et al.</i> (27).
Do.	+					Primordial gonad less sensitive in male than in female, and less sensitive than secondary gonad in both sexes.	Tazima <i>et al.</i> (26).
<i>Oryctolagus cuni- culus.</i>	+					Necrosis.	Heller (9).
<i>Mus musculus</i>	+					Prolongation of inter- and prophase, stoppage of proliferation, prob- ably disturbed DNA synth., ne- crosis.	Bryan <i>et al.</i> (2).
Do.	+			+	+	Necrosis in spermatogonia, re- arrangements in spermatids. Spermatozoa more sensitive in vas deferens than in testis.	Russell <i>et al.</i> (18).
<i>Macaca mulatta</i>	+	+				Gonia: After 400 r, 11 days later: chromosomal disturbances in 68%, 2 years later, in 11% of gonia. Auxocytes: inversions.	Dubin (5) Tinyakov <i>et al.</i> (28).

+ = Reported to be sensitive.

— = Reported to be insensitive.

ing of metamorphosis within a cyst. Here again, the possibility exists that disturbance of the cyst cell may affect all spermatids so intimately associated with it. If the spermatocyst protects its contents against harmful effects that may occur in the liquid intermedium, the extratesticular, free sperm should be more vulnerable than the protected testicular sperm.

The chromatin of the sperm head is in an extremely compact form. In such a stage, the vast majority of the genes are supposedly inactive. The functions of a spermatozoon are reduced to the chemotactic orientations and movement towards the egg; most of the genetic message can remain in dormancy. This explains why harmful mutagenes seldom affect this very specialized haploid cell.

RADIOSENSITIVITY OF DIFFERENT PHASES

OUR aim should be to evaluate the gametogenesis as a target of any sort of treatment, but the fact is that we know more of the radiation effects than of other types of treatments. Therefore we will try to compare the sensitivity of stages with the help of radiation data. It should be kept in mind that treatment by other factors—chemicals, temperature, or illumination (photoperiodism)—cause physiological or genetic changes in gametogenesis.

Table 1 contains a restricted but representative collection of data on the radiosensitivity and effects of radiation in different stages of gametogenesis of some animals.

Because *Drosophila* are very suitable objects and genetically so well studied, it has been possible to detect the kind of induced mutations by planned matings. Almost all authors agree that the post-meiotic stages, especially the spermatids, are highly sensitive. Because few effects have been obtained from treatment of spermatogonia, some authors thought that they are very resistant. Later it was discovered that they are so sensitive that great numbers of them die when treated. Thus observations of the relatively high sensitivity of spermatids, as compared with gonidia, may be largely due to the technique used. Cytological checking reveals the cell deaths and coarse rearrangements, but ignores gene mutations, whereas the genetic method tends to overshadow the cell death.

Unlike *Drosophila*, mammals are inconvenient objects for detailed genetic analyses. Here the checking technique has been mainly cytological.

The spermatogonia are considered the most sensitive stages. Their vulnerability seems to be much higher than that of later stages, because only low doses are needed to produce remarkable effects. The inter- and pro-phases are prolonged, proliferation of secondary gonidia stops, and necrosis occurs. An aspermic period results.

Data available from oogenesis are less numerous, but also suggest sensitivity differences between phases. Experiments by Whiting (33, 34) with the wasp *Habrobracon* showed phases of different radiosensitivity during the oogenesis. Oogonia are injured badly by 2,500 r; treatment of the early meiotic prophase results in larval death in the subsequent generation, and treatment of diakinesis results in death after hatching; treatment of metaphases results in quicker death. The ovarium may suffer atrophy and the total number of eggs may be reduced (7). It seems that there is no essential sex difference in the sensitivity pattern of gonidia in *Drosophila* (14), nor in *Bombyx* (26).

In the mouse, the young oocyte has been long known to be very sensitive (17). Mandl (13) found resistance in oocytes 5–35 days before estrus, but an increasing sensitivity shortly before estrus, from late dictyotene to metaphase I. Similar results are reported by Harvey and Chang (8) in the golden hamster.

To conclude this short survey, we can state that there seems to be sensitive phases distributed throughout the course of gametogenesis, but that certain phases, especially gonidia and spermatids, are extra sensitive. It also seems possible that the kinds of effects depend in some degree to the stage treated.

SPECIAL CHARACTERISTICS RELEVANT TO RADIOSENSITIVITY

The Chromosomes

A NUMBER of cellular variables in plants are correlated with radiosensitivity. Experiments by Sparrow (22 and earlier papers) have helped to demonstrate the role of chromosome number, size, and structure in radiosensitivity. Big size, low number, and acrocentry mean vulnerability; opposite characteristics mean resistance. In other words, the bigger the chromosome, the bigger the chance that part of it will be lost by a random fragmentation. Similarly, an acrocentric chromosome, with only one arm, may lose up to 100 percent of its

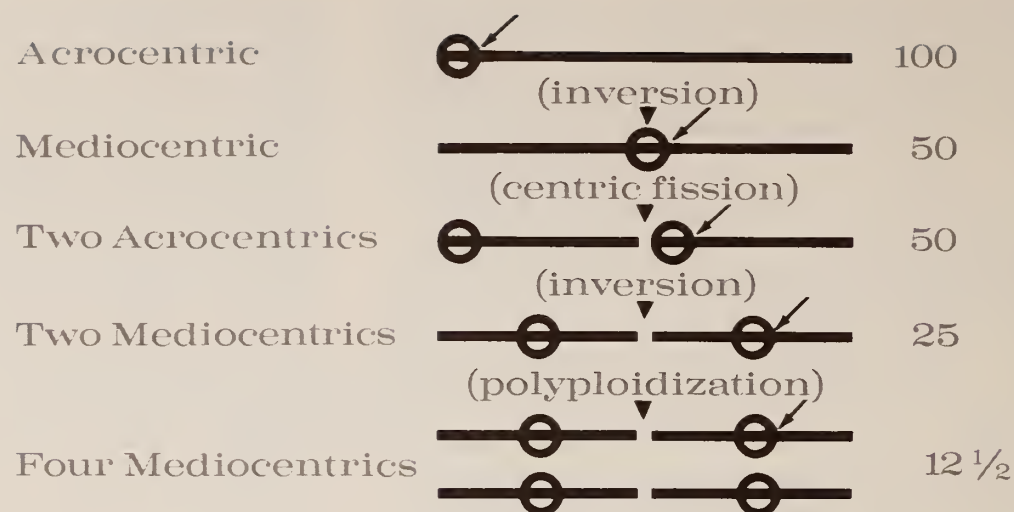


FIGURE 4.—AN EXAMPLE OF HOW THE POSITION OF CENTROMERE AND THE CHROMOSOME SIZE AND NUMBER AFFECT RADIOSENSITIVITY. Maximum loss caused by a single fragmentation shown by thin arrows, and given in percentages at right. This series of changes is thought to occur in one karyotype through rearrangements mentioned in brackets.

genetic material, whereas a mediocentric one can lose only a maximum of 50 percent by a single fragmentation (fig. 4). Furthermore, the higher the chromosome number, the smaller is the percentage of genes removed by a single cut from the chromosome set. Consequently, the same genetic material divided in many chromosomes is better protected than if it would form fewer chromosomes. When the chromosome number increases by polyploidization, an extra protective factor appears: Losses in one chromosome set are genetically covered by the additional homologous sets. Haploidy, consequently, must be the most sensitive degree of ploidy. It may facilitate rapid manifestation of induced mutations immediately after meiosis. In insect gametogenesis, other ploidy differences than those caused by reduction division either appear in sporadic single cells of little importance, or occur in parthenogenetic insects, where polyploid series are known (24).

Because the chromosome arms are kinetically inactive, they must be guided by the centromere in anaphases; if connection with the centromere is lost, the arm is lost sooner or later. This holds true in species with localized centromeres. If the centromeres are diffuse—spread all along the chromosome as in Hemiptera and Lepidoptera—all fragments caused by treatment should be capable of metaphasic orientation and anaphasic movements. Such

chromosomes would not suffer immediately from fragmentation, although difficulties may arise later in fragment heterozygotes.

Species with large nuclear volume are more sensitive than those with small nuclei. Furthermore, a positive correlation exists between the nuclear volume and amount of DNA in the nucleus. This suggests that such a correlation should also exist between the nuclear volume and amount of chromatin, and between the radiosensitivity and amount of chromatin per nucleus. Thus, species with big chromosomes should have large nuclei, much DNA, and be radiosensitive. Of course, a given amount of DNA can form numerous small chromosomes, which increases the resistance. This has been established in plants. The direct correlation is not between the total amount of DNA per nucleus and the radiosensitivity, but between DNA per chromosome and radiosensitivity.

Further chromosomal characteristics linked with radiosensitivity are the amount and distribution of heterochromatin. It is supposed to be more breakable than euchromatin and is less frequent on important genes. Therefore its loss should be tolerable. Because it is often located near the centromere, it may facilitate whole-arm rearrangements.

The mitotic rate also affects the sensitivity. Because stages of division, including the DNA replication, are more sensitive than intermitotic periods,

rapidly dividing cells should be sensitive. This is probably the reason why secondary gonads are so vulnerable. Tazima and Kondo (27) found that secondary spermatogonia of *Bombyx mori* are more affected by chronic irradiation than by acute, apparently because sensitive division stages are affected with more probability in chronic irradiation. The primordial gonads—cells with a low division frequency—were more vulnerable from acute doses. On the other hand, long intermitotic time helps radiation effects to accumulate in the cell. In this respect, gametogenesis with a prolonged prophase seems susceptible, especially in the females, but also in males having a second growth period of long duration in the meiosis.

Although most of these observations are based on plants, they concern cellular properties so fundamental that they should apply for animals as well. Thus, when checking gametogenesis for irradiation, attention should be paid to such characteristics. Modifying Sparrow's (22) list of factors tending toward high sensitivity in plants, we get the following tentative list for insect gametogenesis:

Factors of high sensitivity—

1. Large nucleus
2. Large chromosomes
3. Low chromosome number
4. Acrocentry
5. Localized centromere
6. Much heterochromatin
7. Slow prophase

In other words, the main characteristics deserving attention concern target size (items 1–2), relation of the amount of chromatin with number, location, and kind of centromeres (3–5), promise of breakability (6), and duration of intermitotic stage (7).

Examples of Physiological Factors

NUMEROUS experiments have shown that presence of oxygen increases radiosensitivity. Oxygen consumption diminishes during prophase and is in its minimum during meta- and ana-phase. Sensitivity of the latter two stages may be partly caused by the increased oxygen tension, especially where the divisions are synchronous, like in gonads and cytes within spermatocysts. The function of such closed systems like spermatocyst and spermatophore in radiosensitivity deserves closer study. They are obviously capable of controlling the oxygen tension

and other ambient influences on their germ cell content. Development and duration of spermatocysts and spermatophores vary much in different insects.

Sometimes very unusual situations occur. Thus in *Lepidoptera*, the control of male meiosis is partially or completely lost at the time of pupation, probably because of hormonal changes. Chromosome conjugation fails, anaphasic irregularities occur, and the so-called apyrenous spermatozoa are formed. These are functionless. Therefore treatment of prespermatid stages of lepidopteran pupae for effects in the next generation is a waste of time. However, the pupae are good for treatment of spermatids and spermatozoa, which are products of the normal spermatogenesis in the larval life (31).

It seems possible that a spermatogenesis tending to such anomalies could be more easily disturbed than a usual one. Kogure and Nakajima (10) reported indeed that apyreny can be induced by radiation of larvae in *Bombyx mori*. This lepidopteran specialty can be perhaps utilized in sterilization experiments.

ATTEMPTS AT PREDICTION

TABLE 2 (p. 34) gives an idea of the variation of principal chromosomal characteristics relevant to radiosensitivity in some insect orders and families. Lepidopteran karyotypes with a high number of small chromosomes provided with a diffuse centromere suggest resistance. In contrast, the longer dipteran chromosomes—few in number, with a localized centromere, and often acrocentric—should form a more vulnerable karyotype. Tertrigid grasshoppers with seven chromosome pairs are obviously not at all comparable with pentatomids having the same number, because the diffuse centromere and moderate chromosome size means an advantage for the pentatomids. Tertrigid and tettigoniid chromosomes look similar, but the much higher number in the latter promises an increased resistance. Such characteristics are, of course, the very basic ones for evaluation of sensitivity. Before attempting any predictions, all characteristics of the gametogenesis, also the extrachromosomal ones, should be considered.

Certainly, general data as in table 2 do not serve as a guide for treatment of a given single species, because surprising differences may hide even within groups known to have little variation of karyotypes. *Coleoptera*, an order with considerably consistent

chromosome relations, may serve as an example. According to data accumulated up to 1960 (20, 21), one out of five beetle species has 10 pairs of metacentric chromosomes of moderate size, most of the remaining deviating only slightly from this pattern. Figure 5 compares some of the karyotypes we have encountered in tropical Alticinae (fleabeetles). Whereas *Homoschema nigriventre* has the smallest known coleopteran chromosome number—four pairs—*Walterianella venusta* has as many as 23 pairs including the giant-size sex chromosomes. Thus, one chrysomelid subfamily shows almost the whole range of chromosome numbers known in coleopterans. We also have unidentified species from Trinidad and Guayana having 22 pairs but no giant sex chromosomes. These latter species are supposedly much more resistant than *Homoschema*. It is more difficult to evaluate karyotypes of *Alagoasa* and *Walterianella*, because we do not know the genetical importance of the giant chromosomes. If they contain important genes, as their euchromatic appearance suggests, these karyotypes may be much more sensitive than expected on basis of the chromosome number only.

SUMMARY AND CONCLUSIONS

THIS survey points out that the characteristics of the insect gametogenesis are variable, and that much of the variation is relevant with results of irradiation or other treatments of gametogenesis.

Although the main rule remains that gametogenesis occurs in insects during the latter part of ontogenesis, usually starting in the pupa and continuing in adults, there are remarkable deviations from this rule even between such limited systematical units as subfamilies. Variation takes place as well in initiation and duration, as in the more special characteristics during the course of gametogenesis. Furthermore, ambient factors like temperature and photoperiod may considerably modify the gametogenesis even in one and the same species, especially when its altitude or latitude range is large.

Contrary to extrachromosomal features of gametogenesis, the karyotype of a species remains practically constant. However, systematically close species may have quite different chromosome number, size, and structure—all characteristics related to radiosensitivity. Even one and the same karyotype suffers changes of sensitivity according to its

TABLE 2.—INSECT GROUPS: CHARACTERISTICS RELEVANT TO RADIOSENSITIVITY

Group	Most frequent chromosome number (n)	Kind of centromere	Size of chromosomes	Most frequent chromosome structure
Mantidae	14	Localized	Large	Meta- and acro-centrics.
Tetrigidae	7	do	do	Acrocentrics.
Tettigonidae	16	do	do	Acrocentrics.
Pentatomidae ¹	7	Diffuse		
Lepidoptera ²	31	do	Small	
Coleoptera	10	Localized		Metacentrics.
Diptera ³	4	do		Meta- and acro-centrics.

¹ One lobe, so-called harlequin lobe, produces function less sperm.

² Pupal spermatogenesis abortive due to apyreny.

³ Achiasmate meiosis in male.

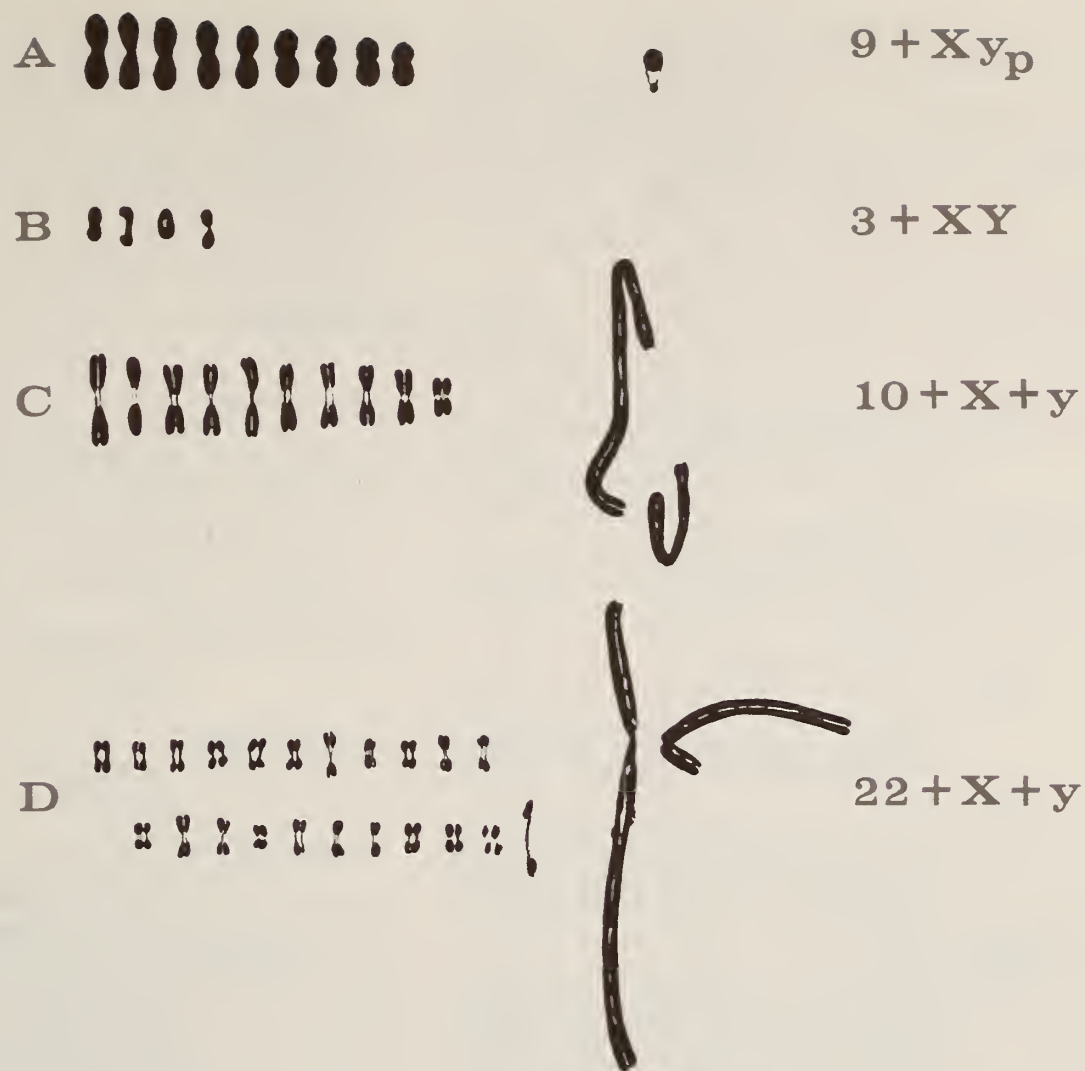


FIGURE 5.—COMPARISON OF SOME COLEOPTERAN KARYOTYPES AT FIRST MEIOTIC METAPHASE OF THE MALE. A. *Epicauta rufipedes* (Duges), a meloid showing the typical nine pairs of autosomes and a parachute-formed sex bivalent of the beetles. B. *Homoschema nigriventris* Blake, an alticid, having only three bivalents and an unidentified sex bivalent. C. An unidentified *Alagoasa* species (an alticid), with 10 autosome bivalents and giant, unpaired sex chromosomes. D. *Walterianella venusta* Schaufuss, another alticid, with 22 autosome pairs and giant, unpaired post-reductional sex chromosomes. Magnification is 1870X.

reduplication and division cycle. This may become an important factor especially in spermatogenesis, where the process is synchronized in the cyst and occurs gradually in some species and in one big wave in others.

The practical conclusion from these observations is that knowledge of the cytology of gametogenesis is desirable in planning treatments for sterility or for effects in the following generation.

Excellent results obtained by the male-sterile method without previous cytological checking show that it may not be a necessity in such practical works, just because the gametogenesis as a whole is a pretty good target, and because it is usually found

in pupae or young adults. The best stage for treatment may be determined experimentally by treating different developmental stages of the animal. But a previous cytological checking orientates in any case—much more so if the gametogenesis to be treated happens to deviate from the common pattern. We have seen that the sensitivity varies according to the phase of gametogenesis, as does even the quality of effects. This condition offers promise that in the future the quantity and quality of results can probably be controlled by treating certain selected phases of gametogenesis. At the same time it means an increased need for information on the cytology of gametogenesis.

To accumulate more data on insect gametogenesis, especially on variation of the extrachromosomal characteristics, it would be desirable not only to direct more work to this special field, but also to include a cytological checkup in all life-cycle

studies—especially when the insect is kept in culture. Such a culture provides a cytologist with abundant material where even the preadult stages are taxonomically properly identified. Few technical problems should remain thereafter.

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Neurons, Brains, and Computers

SOME people fear eventual competition between men and machines for rule of the world, but the real conflict may come between individuals and organized society, according to Prof. Heinz Von Foerster, founder and head of the University of Illinois Biological Computer Laboratory. In a recent lecture Von Foerster discussed these common semantic traps in understanding computer research: "Do machines think?" and, "Can we build a brain?"

To the question, "Do machines think?" Von Foerster explained that the brain and a computer arrive at the same result by different methods. "We don't know how the brain multiplies, adds, or takes the square root, but we're pretty sure that it's not by the digital process used in computers."

When asked to give a definition of intelligence, Von Foerster quoted his colleague, Prof. Ross Ashby: "All information processes appear to be intelligent before we know how they work. When we know how they work, there no longer seems to be magic attached to them." Part of the flavor of intelligent behavior is that, to a certain extent, it is unpredictable.

The question "Can we build a brain?" is irrelevant because it is equivalent to asking, "Can we build X?" when we don't know what X is. The study of the brain demands a different approach, Von Foerster explained, because it is a complex system with very many strongly interacting components. Classical science has been successful until

now because it has been able to isolate the various components and to examine the complex universe step by step. But, he said, one can't open the brain and chop out sections to study them separately.

"Take a colony of about 10 million flatworms, each of which possesses 1,000 neurons. You have approximately the same number of neurons in this colony as are present in a human brain. Now if one removes 1,000 flatworms from this colony, there won't be a very noticeable change in the behavior of the group of flatworms. However, if one removes a corresponding 1 million neurons from the brain of an acquaintance, one will immediately notice a very distinct change in his behavior."

Consequently, the human brain poses a different problem, because it cannot be taken apart and examined. The results of its functions as a whole must be observed.

Many techniques developed by cyberneticists to study the functions of the brain may also be applied to the study of society where, comparable to the neurons in the brain, individuals in a society are strongly linked to each other. And, also comparable to the neurons, the individual may not know what society as a whole may know. It is here, Dr. Von Foerster ventured, where the conflicts between the individual and society may be discovered.

From: *Engineering Outlook*, Vol. 6, No. 6, June 1965. University of Illinois, Urbana.

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NITROGEN FERTILIZERS:

Progress and Problems

Lewis B. Nelson and Roland D. Hauck

NITROGEN fertilizer use has increased spectacularly in recent years. Research on nitrogen has progressed in the same period, but not proportionately. Problems that have plagued nitrogen users for years are still with us. However, they are no longer little problems; their economic importance has multiplied as nitrogen use climbed. New problems also have appeared, particularly those associated with new kinds of nitrogen fertilizers and higher rates of application.

Nitrogen is the most used plant nutrient. U.S. consumption has risen from 759,000 short tons in 1946 to about 4 million tons in 1964. World consumption increased from 2.2 million tons to around 13 million tons in the same period.

The uptrend is expected to continue. Greatest potential for increase is in developing countries and other areas now using very little nitrogen. Industry in the United States and elsewhere is expanding production capacity to meet anticipated needs.

Advances in agriculture and in fertilizer technology have been major factors behind the nitrogen upsurge.

Use of natural gas and petroleum byproducts as sources of hydrogen and the development of increasingly efficient manufacturing plants have reduced the cost of synthesizing ammonia and con-

tributed to abundant supplies of inexpensive nitrogen for direct application and the manufacture of high-analysis nitrogen fertilizers. More efficient marketing and distribution also have helped reduce the cost of nitrogen.

The constant struggle for more efficient farm production to counter the cost-price squeeze has encouraged American farmers to apply nitrogen at heavier rates and to more acres. It also has led to replacement of nitrogen traditionally produced by legumes in crop rotations with chemical nitrogen. In addition, improved crop varieties have made higher rates of fertilization more profitable.

How much nitrogen use will increase is a matter of intense speculation. The average rate of application is only about 13 pounds of nitrogen per acre of arable land in the United States, which produces and consumes more than any other nation. In 1959 (the last year for which data are available), no nitrogen was applied to 39 percent of the corn acreage, 80 percent of the sorghum, 27 percent of the cotton, 67 percent of the wheat, and 92 percent of the tame hay and cropland pasture. Many farmers apply less than half the amount recommended by extension services. Rates of N per acre of fertilized crop in 1959, for example, were 41 pounds for corn, 54 for sorghum, 64 for cotton, and

28 for tame hay and cropland pasture.

Nitrogen rates are much higher in some countries. Great Britain fertilizes nearly all its agricultural land. Average rate is about 60 pounds of nitrogen per acre. The Netherlands uses about 190 pounds, and Japan about 110 pounds.

Nitrogen use in developing countries is still insignificant in relation to the total need. India, for example, applies only 2 pounds of nitrogen per acre of arable land, Brazil about 3 pounds, and Turkey less than 1 pound. Raymond Ewell in a recent address before the American Chemical Society¹ postulated that nitrogen usage in developing countries must approach 16 million tons by 1980 to realize minimum nutrition standards. According to G. W. Cooke,² "The need for fertilizer nitrogen, and the returns from using it, are likely to be greatest in the humid, tropical regions that use little or none at present; there, growth is so quick that two or three crops may often be taken in a year, and potential production is much higher than in most temperate regions." Increased use of nitrogen of course is not a sole cure for food shortages; but without it, food production cannot be increased appreciably.

Significant changes have occurred in recent years in the forms of nitrogen (N) used, with a definite trend toward the higher analysis materials which reduced handling and transportation costs. Worldwide, ammonium nitrate (33.5 percent N), urea (45 percent N), and nitrogen solutions are gradually replacing ammonium sulfate (21 percent N), calcium nitrate (15.5 percent N), and calcium cyanamide (up to 22 percent N). Consumption of nitrogen from ammonium nitrate, in fact, now exceeds that from ammonium sulfate, which dominated world use for years.

In the United States, consumption of anhydrous ammonia (82 percent N) for direct application now exceeds that of any other material. In the year ended June 30, 1963, anhydrous ammonia supplied about 26 percent of the nitrogen for direct application (about two-thirds of all nitrogen used is for direct application) as compared to 13 percent from ammonium nitrate and 12 percent from ni-

trogen solutions (compounded largely from ammonium nitrate or urea or both). Urea use, while increasing, accounts for only 4 percent and aqua ammonia for about 3 percent. Low-analysis materials have virtually disappeared in the United States and are being replaced gradually in the world market.

Nitrogen consumed in mixed fertilizers remains important, although the proportion has been slowly declining as more and more of the straight nitrogen materials are used in direct application. The average nitrogen content of mixed fertilizers has increased consistently over the last decade to over 7 percent today, primarily because of increased use of the various ammonium phosphates.

Nitrogen Transformations in Soils

AN understanding of what happens to fertilizer nitrogen from the time it is added to the soil until it is taken up by the plant or otherwise lost from the active soil system is extremely important in developing new fertilizers and in improving fertilizer and management practices. Unfortunately, as is the case for many complex biological systems, our knowledge is limited. Many of the ideas concerning our knowledge of the soil-nitrogen fertilizer system are indicated in a rough schematic diagram adapted from Jansson.³

Fertilizer nitrate (NO_3^-) added to the soil becomes part of a soluble NO_3^- pool that is available for plant uptake or for movement with the soil water. Under conditions of limited oxygen supply, biochemical reduction of NO_3^- to N_2 and N oxides can occur. In the presence of ammonium (NH_4^+) only a small fraction of NO_3^- will enter the active internal nitrogen cycle of the soil.

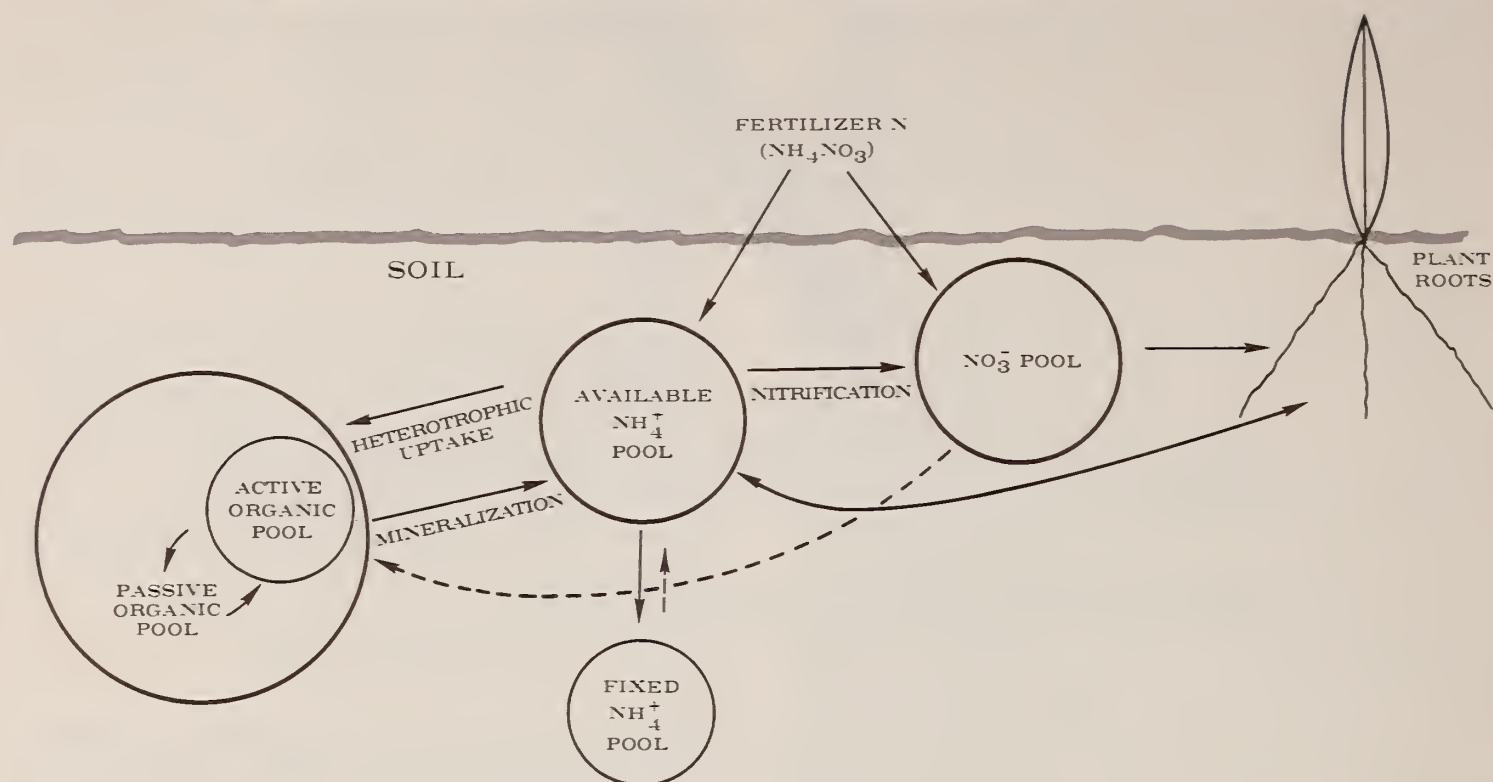
Ammonium ions, for the most part, enter actively into an internal nitrogen cycle which involves a complex of mineralizations and immobilizations during which soil organisms draw upon available carbon and nitrogen for their cell needs. Upon addition of fertilizer NH_4^+ , the NH_4^+ pool in the soil is suddenly increased. A fraction of the NH_4^+ ions can be trapped within the interlattice structure of certain inorganic colloids or otherwise retained and thus removed for an indeterminate

¹ Ewell, Raymond, 1964, *Famine and Fertilizer*. Chem. & Eng. News, 106-117, Dec. 14.

² Cooke, G. W., 1964, *Nitrogen Fertilizers: Their Place in Food Production, the Forms in which They Are Made, and Their Efficiencies*. Proc. The Fertiliser Society, London, 80. 88 pps.

³ Jansson, S. L., 1958, *Tracer Studies on Nitrogen Transformation with Special Attention to Mineralization-Immobilization Relationships*. Kgl. Lantbruks.-Hogskol. Annals 24: 101-361. (In English.)

FIGURE 1.—SCHEMATIC DIAGRAM OF SOIL-NITROGEN FERTILIZER SYSTEM.



time from the internal N cycle. Exchangeable NH_4^+ (adsorbed on the surface of the soil particles) is immediately available for plant uptake, nitrification, or immobilization by heterotrophic soil organisms. All three may proceed simultaneously until the surplus ammonium pool is used up. During this period, additional NH_4^+ may be added by mineralization of soil organic matter.

Unless a large excess of NH_4^+ is added, the NH_4^+ pool in the presence of an adequate supply of energy material is just large enough to meet the demand of the heterotrophic organisms. Ammonium is thus temporarily immobilized. However, if the immobilization demand is met and NH_4^+ ions still exist in the pool, most of the remainder will be taken up by higher plants or will be nitrified and enter the NO_3^- pool. Thus there is competition between the nitrogen-immobilizing heterotrophic organisms, the nitrifiers, and the plant roots for the NH_4^+ nitrogen. The heterotrophs are the most successful of the competitors under low NH_4^+ levels and an adequate energy supply.

Much of the freshly immobilized N apparently exists in microbial tissues which are subject to rapid decay and regeneration. This active organic pool makes up only a small fraction of the total soil organic N pool, but contributes somewhat to the larger pool through additions of aged microbial tissue and residues.

The bulk of the soil organic matter, the passive

organic pool, does not participate actively in soil nitrogen cycles because of its resistance to biological attack. However, it is subject to slow mineralization, releasing nitrogen which is drawn into the turnover cycle or contributes to the NH_4^+ and NO_3^- pools.

It is virtually impossible to follow completely the pathway of fertilizer N in the soil. An investigator usually can measure only the changes occurring in the inorganic and fractions of the organic phases. Established equilibria in the system can be easily upset through fertilizer addition, and variations in crop uptake, soil moisture, leaching, temperature, crop residue additions, and a host of other factors. Effects of fertilizers upon mineralization of organic fractions or, for that matter, how much nitrogen is actually contributed by the soil organic fractions are difficult to determine, even with tagged nitrogen (using N^{15}).

A great deal of basic research will be required to sharpen our understanding of the changes that take place when N is added to the soil. When asked at a recent nitrogen symposium to outline important areas for research, Francis E. Clark of ARS, USDA, who has spent his lifetime on nitrogen research, replied, "Simply anything and everything having to do with soil N."⁴

⁴ Tennessee Valley Authority, Proc. of the Nitrogen Research Symposium. 110 pps. Published by TVA, Wilson Dam, Ala., 1964.

THE plaguing problem of low recovery of fertilizer N by crops remains largely unsolved. A large share of agronomic nitrogen research in recent years has been directed at various facets of this problem. These efforts have resulted in a better understanding of the various pathways leading to low recovery.

There is general agreement in long-term field experiments that 25 to 50 percent of all fertilizer N applied to the soil is not recovered. This means that of the almost \$3 billion that the world's farmers spent for nitrogen fertilizers last year, \$3/4 to \$1 1/2 billion was spent for nitrogen that did not benefit crop production. Even under the best of conditions and by applying the full knowledge gained to date, losses ranging from 10 to 20 percent are considered unavoidable.

Part of the fertilizer N is lost through leaching and surface runoff; some may remain in the soil in forms positionally and chemically unavailable to the plant in reasonable lengths of time; and part is lost to the atmosphere. Amounts lost vary from nil to very large depending on soil and climatic conditions, kind of fertilizer, and cropping and management practices.

Leaching undoubtedly is a major source of loss in humid and irrigated regions but one which can be minimized most easily. Nitrates along with their accompanying cations are readily soluble in the soil water and can move with excess water below the root zone or into the ground water. Leaching loss is greatest where rainfall greatly exceeds evapotranspiration. Such loss is most severe on coarse-textured soils of low water-holding capacity, on fallow lands where nitrates accumulate, for shallow-rooted crops, and where the fertilizer N is added in amounts or at times leading to NO_3^- accumulation during periods when rainfall exceeds evapotranspiration. Fortunately, the period when rainfall exceeds evapotranspiration throughout most of the humid regions of the United States coincides with the period when no crops are grown and only small amounts of residual NO_3^- are available for leaching. Under irrigation, loss is most severe when the wetting front is allowed to move below the potential rooting zone of the crop.

Proper management practices can reduce leaching losses and greatly improve nitrogen recovery. There are numerous possibilities: Avoidance of

large residual nitrogen carryovers from the cropping season; avoidance of fall or early spring nitrogen applications where winter and spring leaching is prevalent; shortening of irrigation runs and avoidance of excess irrigation; and the use of smaller and more frequent nitrogen applications on sandy soils.

Inasmuch as the mechanics of leaching losses are fairly well understood, the greatest research need seems to be in obtaining additional data under specific soil conditions in different climatic areas to further determine the seriousness of such losses and to guide and refine recommendations. Certainly, improvements in recommendations could be made through closer collaboration between soil physicists and soil fertility specialists.

Surface-applied N also may be lost in runoff during flash storms coming soon after application. The seriousness of such loss is unknown because practically all studies made at the old soil erosion stations did not involve nitrogen fertilizers and were concerned with total analysis rather than soluble constituents. A few exploratory studies using modern fertilizer practices would appear justified.

Fixation or retention of fertilizer N by soils is another cause of reduced fertilizer efficiency. One mechanism involves interlattice trapping of NH_4^+ by clay minerals (not to be confused with surface sorption of NH_4^+ which is readily available to plants), principally of the hydrous mica type. Possible also is the reaction of NH_4^+ with active organic matter resulting in formation of ammonia-lignin-cellulose complexes. Most recently it has been shown that NH_4^+ in association with aluminum, iron, calcium, and magnesium can precipitate as complex ortho- and pyro-phosphates. Just how important or how prevalent these mechanisms for removal of available N are is not known.

Fertilizer N also is lost by volatilization from soil as ammonia (NH_3), N oxides (NO and N_2O), and as nitrogen (N_2) gas. Volatilization presents a complicated and difficult problem, although many observations have been made which, if applied, could substantially reduce this loss.

The conditions under which NH_3 is evolved are fairly well understood. Ammonia can volatilize from any surface application which results in high ammonium concentration and high local pH, such as broadcast application of ammonium salts to neutral or calcareous soils, shallow injection of anhydrous ammonia, or surface applications of urea on

bare or grass-covered soils. Most NH_3 losses can be avoided by the simple expedient of soil incorporation. Yet, simple as this is, large amounts of NH_4^+ -containing fertilizers and urea continue to be surface-applied under conditions certain to lead to severe volatilization losses.

Much of the unaccounted-for nitrogen loss may be the result of denitrification processes, either biochemical or chemical. Bacterial reduction of NO_3^- to N_2 gas or N oxides in anaerobic microsites may be more important than previously thought. Also, nitrogen fertilizers are now banded in sufficient concentrations to bring about a variety of chemical reactions involving biologically formed nitrite (NO_2^-) in which gaseous forms of nitrogen are produced.

Much remains to be done in determining the extent and conditions under which N_2 gas or N oxides are lost from the soil. Nitrogen not recovered in the soil or plant now is currently presumed lost without either identifying or measuring the gases evolved. No direct quantitative measurements using closed systems and the nitrogen isotope N^{15} have as yet been made on a greenhouse scale. Field measurements, regardless of the difficulty, would seem a necessity. Only when the kind and magnitude of the losses are identified and the factors affecting them are understood can we hope to devise means to improve recovery.

Possibilities for Improved N Recovery

THERE are a number of ways, besides those already mentioned, in which nitrogen recovery and efficiency conceivably might be improved. Foremost among these in effort and interest is the development of slow-release chemical nitrogen fertilizers. Many cherish the hope that such fertilizers would minimize leaching and volatilization losses, lessen damage to plants, and permit closer matching of the plant's nitrogen needs with the rate and amount of N release from the fertilizer.

One approach is to develop compounds that release nitrogen slowly because of their limited water solubility or slow rate of degradation. In such compounds, the amount of surface area exposed determines the rate of dissolution. Varying the particle size thus can vary the rate of release, with the larger particles releasing their nitrogen most slowly. Magnesium ammonium phosphate, crotonylidenediurea

(Floranid), isobutyridenediurea (I.B.D.U.), glycoluril, and oxamide all exhibit this property and the first three are produced commercially. The slow release of the ureaforms (produced commercially) and the triazines depend also upon their resistance to microbial decomposition. All are costly to produce, which has limited their use largely to turfs, gardens, and specialty crops.

Another approach is through coating soluble nitrogen compounds with some material that will delay release or slow the rate of release. Waxes, paraffins, acrylic resins, polyethylene, vinyl acetate, latex, gums, oils, and sulfur have been used experimentally. Slow or delayed release is achieved through one or more of the following mechanisms: (1) Water vapor entering through the coating until the internal salt solution pressure is sufficient to break the coating; (2) controlled or inhibited movement of dissolved salt out through tiny pores in the coating; and (3) degradation of the coatings through microbial and abrasive action. Although coatings can be effective, they are costly to apply and lower the nutrient content of the product. It is extremely difficult to coat fertilizer particles uniformly in large-scale plant operations and, unless this is achieved, coatings are of little value. The fact that sulfur is a low-cost noncrystalline material and has value as a secondary nutrient is the reason for TVA's work with sulfur coatings.

Natural organic materials which are resistant to rapid microbial decomposition also exhibit slow-release properties. Use of natural organics as sources of nitrogen in mixed fertilizer has decreased considerably. Still, a number of organic products are on the market, such as processed sewage and garbage and ammoniated brown coal and lignite. The N content of such products is low and costs per pound of N are high, especially when the products are transported any distance. However, the growing problem encountered by municipalities in disposing of sewage and garbage undoubtedly will lead to an increase in their processing for soil application.

Probably a great deal more effort is being placed on developing slow-release nitrogen products than is justified in view of the general lack of information as to their potential agronomic value. For example, little is known of the extent to which small amounts of nitrogen released slowly are tied up in the cellular structure of micro-organisms and must

await mineralization before becoming available for plant uptake. If cellular tieup is appreciable, the rate of release to the plant may be too slow to supply its needs under most situations. Studies keying in soil microbiological studies with basic plant physiology would seem of prime importance not only in understanding how to use the slow-release materials at hand, but also in guiding their logical development.

A more sophisticated approach to the problem of increasing nitrogen fertilizer efficiency is through the development of nitrification inhibitors. Dow Chemical Co. currently is marketing 2-chloro-6-(trichloromethyl)-pyridine, "N-serve," which is re-

ported highly toxic to soil organisms that convert NH_4^+ to NO_2^- . The product has been shown to be effective in sandy soils under severe leaching conditions, in clay loams subject to denitrification, and under cool soil conditions when applied prior to planting. Thiourea biuret, dicyandiamide, and other compounds also have been investigated.

Continued search for specific inhibitors in regard to blocking ammonium oxidation should prove of agricultural benefit. Such an inhibitor should be specific in blocking conversion of NH_4^+ to NO_2^- , be able to move with the fertilizer through the soil, and not be toxic to the growing plant or subject to rapid degradation by soil chemical or



microbiological action. An effective urease inhibitor that would block NH_3 formation until urea is washed into the soil would greatly increase the versatility of urea.

Closer matching of the nitrogen supply with actual crop needs also should improve the efficiency of nitrogen use. Theoretically, the supply of nitrogen available to the crop should coincide with its rate and pattern of seasonal uptake, with none left over in the soil for subsequent loss. The problem is complicated because the nitrogen needs of crops differ both in amount and timing. For example, corn has a low nitrogen requirement during the first 4 to 6 weeks of its growth, but needs as much as 4 pounds per acre per day during its most rapid period of growth. After tasseling and silking, the uptake rate falls off sharply, since during the fruiting period the plant largely maintains itself on the nitrogen reserves in the leaves and stem. This contrasts sharply with grass forages in which nitrogen uptake parallels the rate of dry matter elaboration, or cotton where a high rate of nitrogen uptake continues until harvest. Obviously the patterns of uptake for various crops dictate quite different nitrogen regimes. In addition, uptake patterns for the same crop in successive years may differ somewhat because of seasonal and fertility variations.

In practice, a farmer may make a single large nitrogen application in the spring aimed at having nitrogen available in sufficient quantities to meet the plant's needs throughout the season and then bear with the luxury consumption and nitrogen losses inherent in the system. Or, he may attempt to match the actual requirements more closely by split applications and hope that rainfall will come at the right time to move the nitrogen into the root zone. While both systems are wasteful, the low cost of nitrogen in relation to the high returns makes both feasible from the economic standpoint.

One hope is that a nitrogen fertilizer can be devised in which the release pattern can be made to coincide with the crop demand pattern. The development of slow-release N compounds in which the rate of release is related to the surface area of the particles offers some encouragement. It might be possible to formulate a fertilizer in which different particle sizes or coated materials were combined in such a way as to approximate the desired release pattern. A practical fertilizer of this type is not now on the horizon. However, experimental slow-

release fertilizers with the desired characteristics can be made from existing compounds to determine the potential of this approach.

Estimating the amount of residual fertilizer N carryover from one crop to another and from one season to another, and the amount of N that the soil organic matter fraction may release to the growing crop would seem essential in any sound N fertilizer program. However, it presents many complications. Laboratory methods have been developed, usually involving biological incubation, but none have been too successful. The transitory nature of residual NO_3^- in soils, the need to consider the NO_3^- contributions of various soil layers in the root zone, and the rate and extent of mineralization of crop residues and soil organic matter fractions all present problems. Many, in fact, question whether meaningful assay methods adaptable for use in soil testing laboratories can be developed. Certainly more knowledge will be required. In the meantime, estimation of available nitrogen reserves in the soil remains largely dependent upon the agronomist's ability to make predictions based on his knowledge of the soils and on management and cropping histories.

Nitrogen Damage

NOT all effects of nitrogen fertilizers are beneficial. It is generally recognized that nitrogen imbalance may delay maturity of certain crops or otherwise adversely affect crop quality; that ammonium sulfate and nitrogen fertilizers containing no metal cations increase soil acidity; and that high concentrations of water soluble nitrogen fertilizers damage germinating seeds and young plants. Also, nitrates can accumulate in plants in quantities toxic to livestock under conditions of high soil nitrate content and adverse growing conditions.

Recently it has been found that free NH_3 released from urea, diammonium phosphate, and anhydrous and aqua ammonia can cause seedling damage. Concentrations of these fertilizers result in a localized zone of high pH which is conducive to release of the toxic NH_3 . Another form of toxicity, also recognized recently, is caused by NO_2^- accumulation in zones of high fertilizer N concentrations. Partial sterilization of the soil in the highly alkaline microenvironment apparently inhibits *Nitrobacter* activity and NO_2^- accumulates in harmful quan-

tities. Not only are young plants damaged, but losses from volatilization may result.

What takes place in the microenvironment immediately around the fertilizer granule or band can markedly affect nitrogen utilization and losses and the degree of phytotoxicity. Concentrations of nitrogen fertilizer salts under present-day rate and placement practices are such that the fertilizer goes into solution more rapidly than it can be acted upon biochemically. The pH around the site may become alkaline, neutral or acid, depending on the nature and concentration of the fertilizer. This in turn determines the kinds of reactions and the intermediate or end products formed. Only by making measurements over decreasingly smaller distances will it be possible to establish the conditions that exist in the microenvironment. Not only should effects of existing nitrogen fertilizers be studied, but each new material should be investigated in its earlier stages of development.

Increasingly heavy use of nitrogen fertilizers may be creating another problem difficult to remedy—subsoil acidity. Nitrogen fertilizers which do not contain a metal cation deplete soil bases as nitrification occurs and the nitrates, along with the cations with which they become associated, leach from the soil. This removal of cations increases the acidity and, in turn, depresses root development and penetration. Shallow rooting limits the amount of water available in the soil for crop growth. Removal of cations from the plow layer is not a particularly disastrous problem since it can be corrected easily and cheaply through liming. However, correcting subsoil acidity is an entirely different matter. Lime does not move appreciably in soils and is extremely costly to incorporate uniformly into subsoils. Continuing attention should be given to the subsoil acidity problem since permanent damage to our most productive soils could result. Maintaining a well-limed surface soil to provide a sufficiency of cations for movement with nitrate into the lower layers may be a practical answer.

Interest has developed recently over the high nitrate content of wells and ground waters. Incidence of methemoglobinemia among infants is reported to be increasing as well as the percentage of potable water supplies having comparatively high levels of NO_3^- . Concentrations of 20 to 25 p.p.m. are considered unsafe for infants. Forty p.p.m.

approaches the toxic level for cattle and other ruminants. Whether the increased concentrations result from increased nitrogen fertilizer use is not definitely established. Studies in Missouri, for example, indicate that high nitrate levels in farm wells are due to their location near barnyards. Continuing studies would seem in order to either establish or refute that poor use of nitrogen fertilizers can contribute to toxic quantities of nitrates in ground waters.

Nitrogen Uptake and Utilization

The role of nitrogen in plant nutrition and growth has received a great deal of attention and apparently is fairly well understood and documented.⁵

Most plants are capable of using both NH_4^+ and NO_3^- forms, although some are better adapted to one or the other. Unfortunately, the interpretation of much of the work on crop preference may be questioned because of failure to consider all effects caused by adverse greenhouse conditions or by other ions associated with the particular form of nitrogen applied. It seems most likely that the plant will take up in greatest amount whichever form predominates in the soil at the time, although age and kind of plant, the root environment, and other factors may be important. Knowledge is particularly deficient on the simultaneous uptake of NH_4^+ and NO_3^- ions at various concentrations of each. It is not known, for example, whether nitrification is actually a desirable biochemical transformation necessary to provide a form requiring the least expenditure of energy in its metabolism by the plant. Such information must be obtained before we can properly assess the value of nitrification inhibitors in terms other than NO_3^- movement and loss, or evaluate the effects on plants of concentrated band placements in which NO_3^- formation is inhibited.

Organic nitrogen compounds continually appear as transients in the soil solution and these may be absorbed to some extent by plant roots. Lysine has been shown to be absorbed by barley, aspartic and glutamic acids by peas, alanine by cress, and humic acid by corn. Urea in sterile culture also has been found to enter the plant unchanged.

⁵ Donald, L., Stangel, H. J., and Pesek, J. T., Jr., 1963, *Advances in Knowledge of Nitrogen Fertilization in the USA since 1950*. In: *Fertilizer Technology and Usage*, pp. 75-129, published by Soil Sci. Soc. Amer., Madison, Wis.

Further investigation might be worthwhile to determine the types of nitrogen-containing organic molecules that can be absorbed, and to determine just how available fertilizer N is to plants after it has undergone chemical or microbiological immobilization into various organic constituents. European and Russian workers have indicated a positive action of humus and other organic matter constituents on the uptake of nutrients, increase in dry matter, and better quality of the produce.

Considerable work has been reported on factors affecting absorption of foliar-applied nitrogen, primarily urea. Use of foliar application has been limited by such problems as leaf burning, nitrogen volatilization, and the higher cost of multiple applications required for uptake in sufficient amount. Potentials for foliar applications are by no means exhausted. It might be possible to stimulate plant metabolism through foliar uptake of organic nitrogen sprays or energy-rich nitrogen-phosphorus formulations such as carbamyl phosphate. Growth regulators that supply nitrogen or nitrogen and phosphorus also may offer possibilities for foliar applications. A number of compounds—triazines, some indole derivatives, β -hydroxyethylhydrazine, N-dimethyl amino succinamic acid and nicotinamide—can increase ion uptake or regulate some phase of plant growth.

Development of New Fertilizers

The old axiom, "A pound of nitrogen is a pound of nitrogen regardless of source," still holds, provided that each material is applied in a manner and under situations most favorable to its use. Efficiency gains in the newer soluble nitrogen fertilizers have been disappointingly small. The problem is that we do not know altogether how to make proper use of each source or, for that matter, how to evaluate it. Too much dependence has been placed on conventional field experiments which usually are too insensitive to measure small differences. Net yield increases alone seem a poor way to evaluate nitrogen sources, since we are dealing with an interplay of factors about which there is little knowledge. It seems possible that certain materials would outperform others if we knew the exact situations or application methods most favorable to their use. On the other hand, hasty condemnation of any low-cost, high-analysis nitrogen fertilizer because of an apparent disadvantage should be avoided.

Only a few years ago urea was condemned by some because of ammonia volatilization resulting from misapplication on soil or plant surfaces. Yet it is now well on its way to becoming one of the world's important sources of nitrogen.

In the development of new fertilizers, manufacturing costs and the nutrient content must receive first attention, since these largely determine the price that the farmer pays for the product. Thus the range of possible nitrogen compounds that might have economic value as fertilizers is considerably narrowed. All must be based at present on synthetic ammonia, the cheapest form of fixed nitrogen. With each step in the transformation to more complex compounds, the manufacturing cost rises and, if the nitrogen content goes down, transportation and handling costs also go up. Increased costs from these sources thus can easily outweigh any economic advantage gained from improved nitrogen recoveries or slightly superior crop responses per pound of nitrogen.

Theoretically, a logical and realistic approach to the development of a new nitrogen fertilizer probably should begin with fundamental research to determine what forms of organic and inorganic nitrogen are most readily absorbed and assimilated by different crops under specific environmental conditions. This approach in turn should be supplemented by basic microbiological and other research to determine exactly the transformations that occur in various forms of nitrogen in the soil environment. Energy relationships of various nitrogen compounds also might be investigated. Whether such approaches would lead to more effective nitrogen fertilizers of economic importance is of course open to question. Such information, however, would be of extreme value in advancing our general knowledge.

Other than the slow-release nitrogen materials, drastically new nitrogen carriers do not appear to be on the horizon. Instead, efforts are being focused largely on practical combinations of known carriers to form new materials. For example, ammonia-sulfur mixtures, ammonium nitrate-zinc, and urea-ammonium phosphate are under development at TVA. Others include mixtures of a soluble and less soluble nitrogen material to supply different amounts of immediately available and residual supplies of nitrogen, addition of acid-hydrolyzing materials to sources such as urea which

form excessively alkaline microenvironments, and a host of combinations each directed toward the better use of a given material in a given situation.

Conclusions

In this brief and by no means complete presentation of the progress and problems of nitrogen fertilizers, it is apparent the basic information is sadly lacking in a number of areas and that such information must be gained if we are to realize maximum returns from the use of nitrogen fertilizers. Certain gaps also exist where information can be gained through applied research. At the same time, we often are not applying what we now know.

Only a handful of scientists in this country are devoting full time to resolving the more difficult problems connected with nitrogen utilization. Also, much of the research here and in other countries is conducted on isolated phases of the soil-fertilizer-plant system without much attention given as to how the work fits into this system.

Greater use of the stable nitrogen isotope N^{15} would seem essential for studying various pathways of fertilizer N applied to the soil and for obtaining direct quantitative measurements on nitrogen loss. High cost of the isotope and its analysis has limited

its use in the past. However, aid in this regard is provided by such programs as the one initiated about 2 years ago in which AEC and TVA have agreed to cooperate in supplying up to 30 grams of N^{15} per year over a 10-year period for research on mutually approved projects that contribute to knowledge relating to the overall nitrogen efficiency problem or to the use of N^{15} as a research tool.

Although low recoveries of fertilizer N are of considerable economic importance to temperate region farmers, the relative importance is probably of much greater magnitude in tropical and subtropical regions. Extended periods of high rainfall and temperature contribute to accelerated nitrogen loss through leaching and rapid decomposition of organic matter. Low soil-base exchange presents new problems of nitrogen fertilizer management. Research on chemical denitrification, atmospheric nitrogen fixation, and organic matter formation has scarcely begun. Because of hunger problems in tropical and subtropical areas, coupled with the fact that numerous land-grant colleges and Federal agencies are participating in development programs, it is imperative to conduct nitrogen research in considerable depth under tropical and subtropical conditions.

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Estrous Cycle Control: A Conference Summary

About a year ago, *Review* published a preview of the Conference On Estrous Cycle Control In Domestic Animals. The proceedings of this conference have now been published as Misc. Pub. No. 1005 by the United States Department of Agriculture in cooperation with the University of Nebraska. The benefits that developed from this conference were ably summarized by H. H. Cole, University of California, Davis. Excerpts of his summary follow:

"Significant progress has been made in the pharmacological control of estrous phenomena in domestic animals. Many of the studies, however, would have been more valuable had the effects of the pharmacological agents been studied in greater depth.

"It would seem that further conventional studies with MAP and CAP could hardly be justified. Certainly we have gone far enough to know that feeding of these compounds leads to considerable synchro-

nization in cattle and to remarkably good synchronization in sheep.

"I [commend] the studies concerning the factors influencing persistence of the corpus luteum, for the studies on the role of the hypothalamus in reproduction and for studies on the role of social and environmental factors in controlling or modifying reproductive activity.

"As a general conclusion, the advances made in estrous control in cycling and in anestrus domestic animals are most gratifying. My plea, however, is that we study reproductive phenomena in greater depth and likewise study the effect of pharmacological agents in greater depth. If we know secretory rates of the various hormones controlling reproductive activity and if we know more accurately the enzymatic reactions associated with specific reproductive activities, we will in turn be able to evaluate more accurately the normalcy of the response to pharmacological agents."



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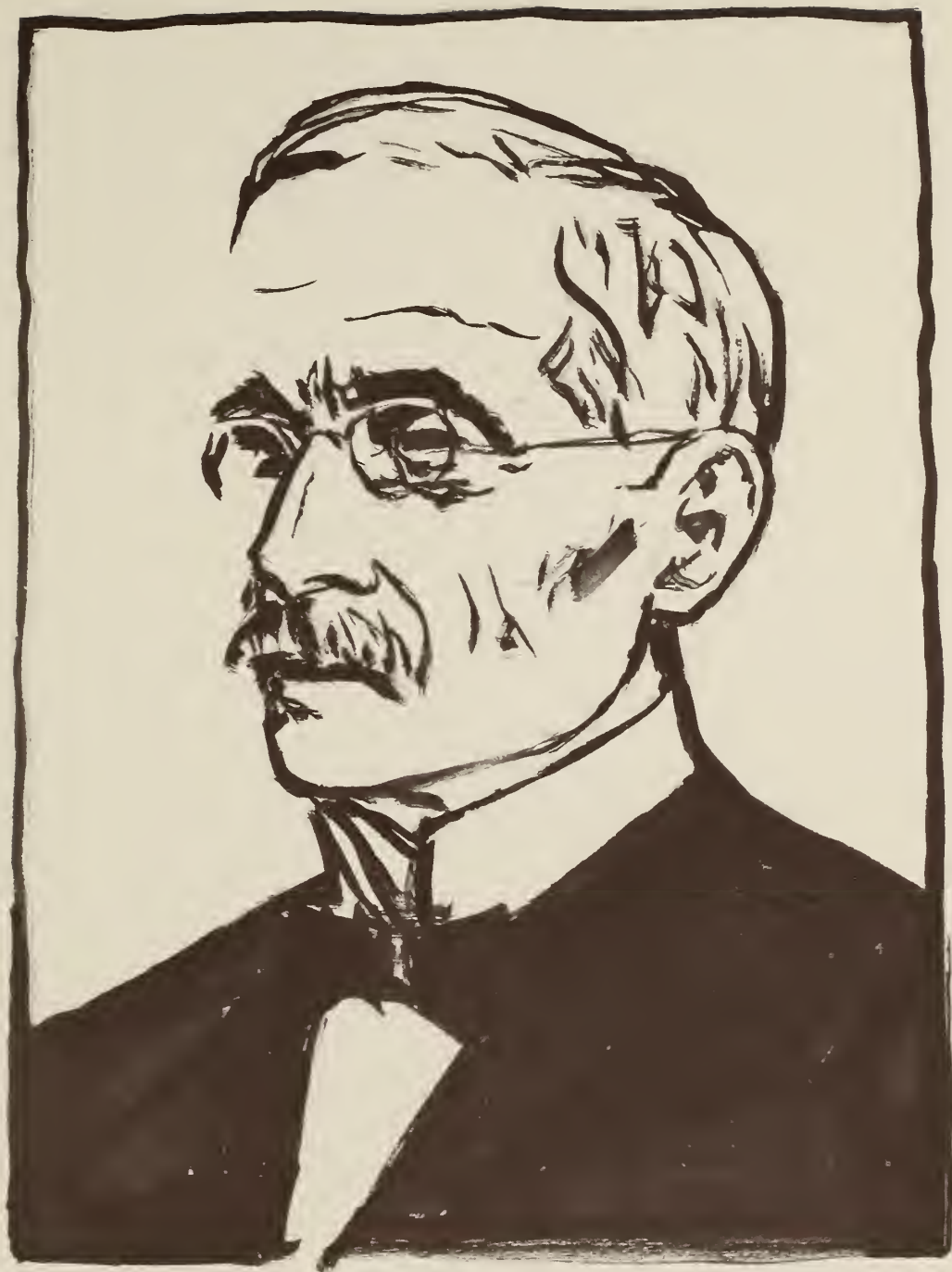
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*“For all of us, the time is short
during which we can justifiably neglect
to kindle and to tend and direct the searchlights of truth.”*

SAMUEL W. JOHNSON
1830 – 1909

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